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PENNSYLVANIA GEOLOGICAL SURVEY

FOURTH SERIES
BULLETIN M 3

THE SILICA REFRACTORIES *of* PENNSYLVANIA

By E. S. MOORE
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DEPARTMENT OF FORESTS AND WATERS
R. Y. STUART, *Secretary*

TOPOGRAPHIC AND GEOLOGIC SURVEY
G. H. ASHLEY, *State Geologist*

HARRISBURG, 1924

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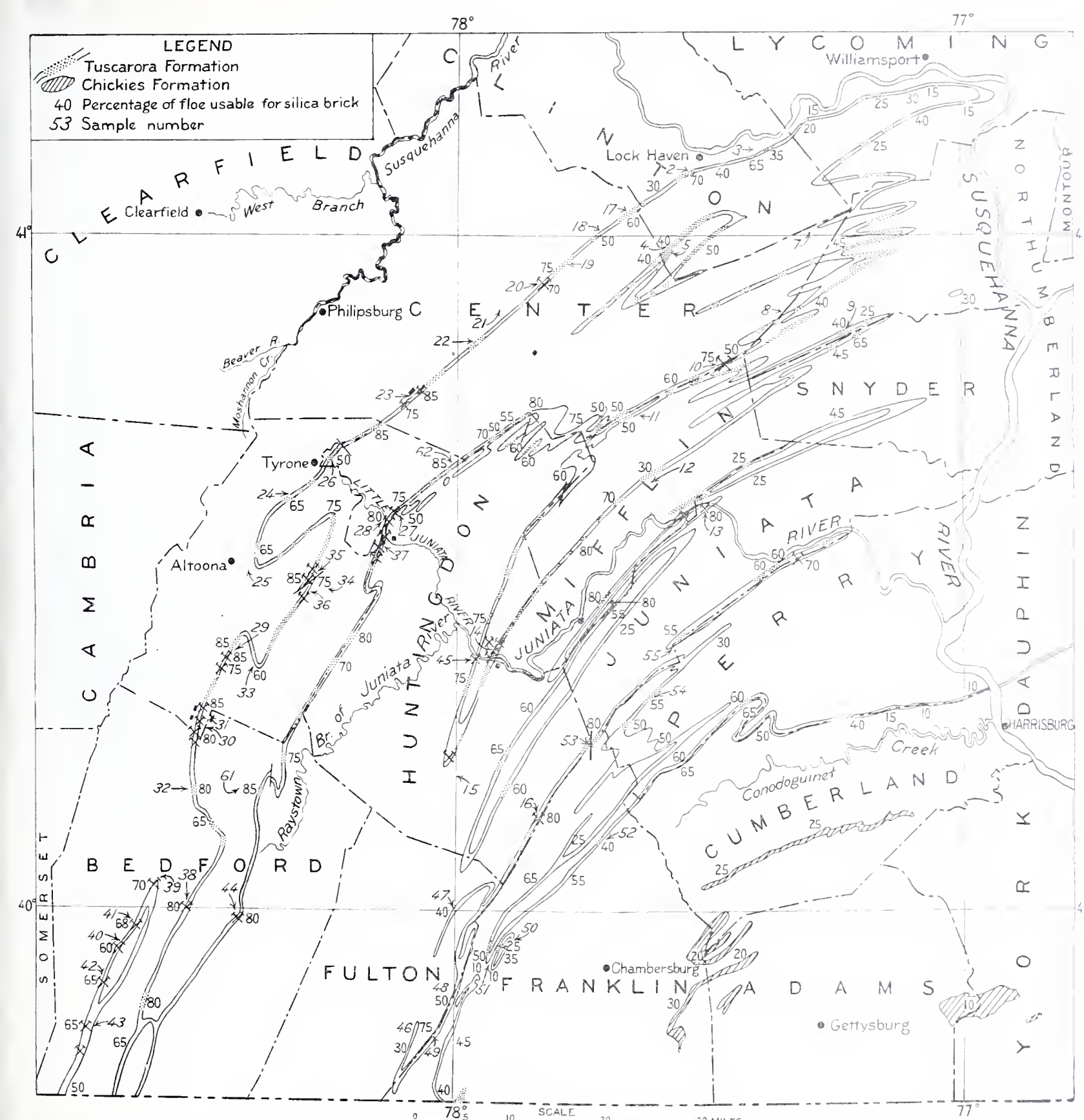

FIGURE 1. Map of central Pennsylvania showing location of Tuscarora (Medi[illegible]) and Chickies quartzites, places where samples were collected, and percentage of floes usable. Floes are represented by stippling, and quarries by crossed hammers.

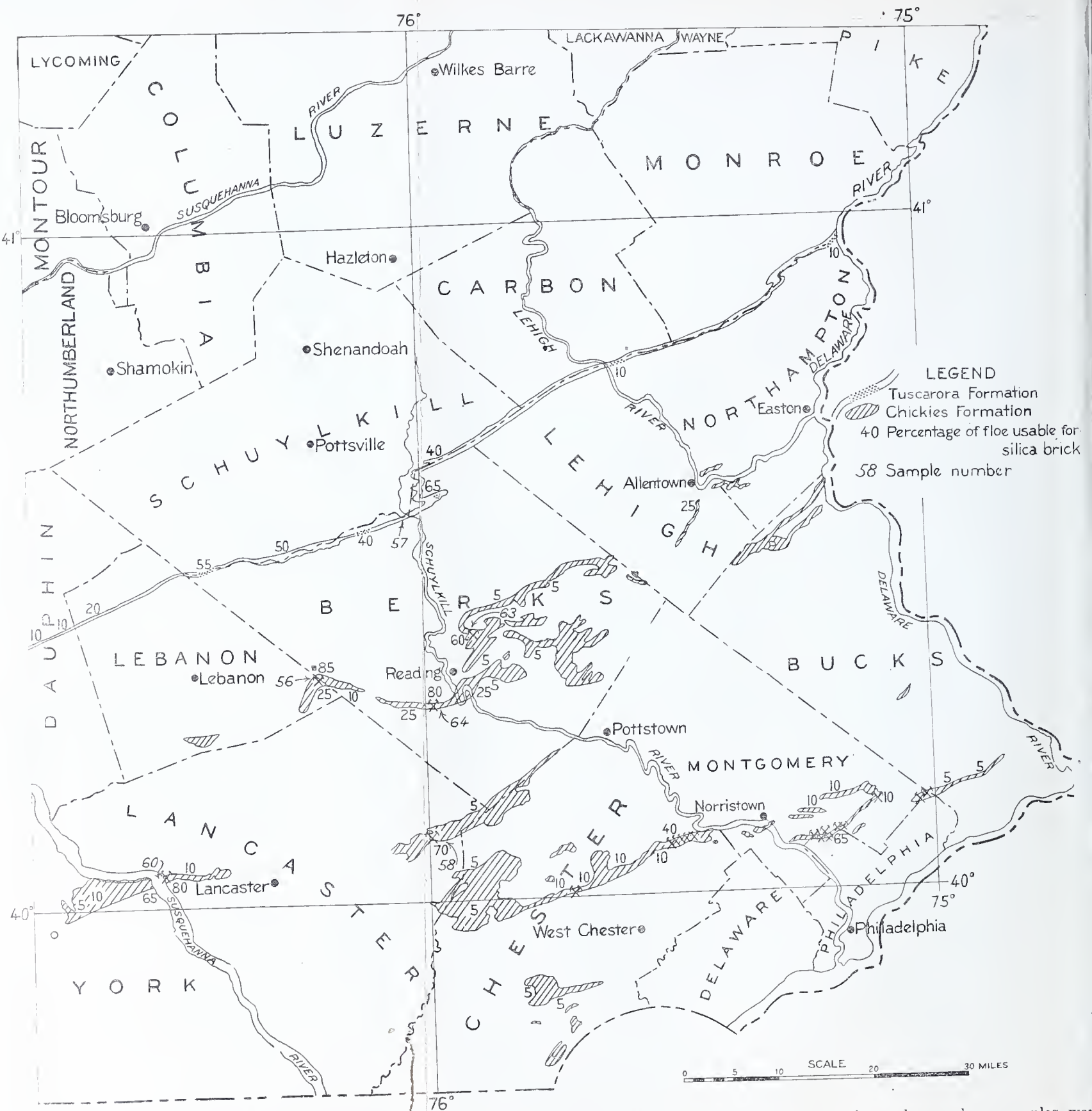

FIGURE 2. Map of southeast Pennsylvania showing location of Tuscarora (Medina) and Chickies quartzites, places where samples were collected, and percentage of floes usable. Floes are represented by stippling, and quarries by crossed hammers.

LETTER OF TRANSMITTAL

R. Y. Stuart, Secretary,

Department of Forests and Waters:

I have the honor to transmit herewith for printing a manuscript and illustrations describing the Silica Refractories of Pennsylvania.

This report is by Professor E. S. Moore, formerly Dean of the School of Mines of State College, assisted by Mr. T. G. Taylor. The field work covered the summers of 1920 and 1921, and the laboratory work the following school years. The report is part of the work accomplished by the Geologic Survey while a Bureau in the Department of Internal Affairs.

Respectfully,

Geo. H. Ashley

State Geologist,

November, 1923.

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The SILICA REFRACTORIES of PENNSYLVANIA

By E. S. MOORE* and T. G. TAYLOR

INTRODUCTION.

At least four substances used as refractories in Pennsylvania have silica (SiO_2) in some form as their main constituent. These are: silica brick; ganister; silica cement; and mica schist. Mica schist is used in the raw condition, ganister both raw and ground, and the other two are manufactured. There is an abundance of raw materials in this State for all four. Pennsylvania is much the largest producer of silica brick in the United States. In 1920 this State produced 73 per cent of the quantity and 71 per cent of the total value of silica brick manufactured in the country. In 1910 the percentage was even higher, the production being about 77.26 per cent of the total quantity produced.[1] The production for 1920 in Pennsylvania reached the equivalent of 182,811,000 9-inch brick valued at $10,629,769. The great development in the iron and steel industry and especially the rapid development of the related by-product coking industry have been responsible for a marked increase in the use of silica brick.

All of Pennsylvania's production, with the exception of that from two plants, comes from one geological formation. This is the Tuscarora quartzite, commonly known in the literature on the subject as the Medina quartzite. This is the main mountain-building formation through Central Pennsylvania and the great talus floes of this rock along the mountain faces are familiar to all travellers through this region. These floes are particularly extensive and striking in the vicinity of Hollidaysburg, Mount Union and Lewistown. They have become a great asset to the industrial life of these communities although the mountain land was formerly regarded as worse than useless. Areas which have been sold for taxes have produced millions of silica brick. The reserves of this rock for future development are exceedingly large.

*Since 1922 Professor of Economic Geology, University of Toronto, Toronto, Ont.
[1]Mineral Resources U. S. Geol. Survey, for 1910-1920.

Because of the importance of the silica refractories in this State the writer, through a cooperative agreement with George H. Ashley, State Geologist of Pennsylvania, and with the assistance of T. G. Taylor, undertook a detailed study of the silica deposits in Pennsylvania. Parts of the summers of 1920 and 1921 were spent in the field mapping the formations from which these materials are derived, collecting samples for laboratory study, and studying the technology of the silica brick industry. Sixty-five large samples were collected for laboratory study of fusibility, chemical composition, and microscopic characters. To Mr. Taylor large credit is due for the laboratory work and he has also proved to be an efficient aid in the field. My thanks are due him for his splendid cooperation in all our work. The laboratory work was done in the laboratories of the School of Mines of the Pennsylvania State College at State College, and we are indebted to D. F. McFarland, professor of metallurgy, for his aid and cooperation in the use of the furnaces in the Department of Metallurgy. While engaged in the field work we experienced the most kindly treatment and hearty cooperation from all the officials of the silica brick and quarrying companies and their attitude has been very much appreciated. It is impracticable to mention all the individuals who took special pains to furnish information or show us courtesies. Because the processes of silica brick manufacture have been standardized and there has been such friendly intercourse between the officials of most of the companies, opinions have been freely exchanged. Probably there are fewer secrets in this industry than in most others.

In securing data for the map (Figs. 1 and 2), the reports of the Second Geological Survey of Pennsylvania were freely used as well as the folios of the United States Geological Survey which cover areas investigated. The Pennsylvania Department of Forestry very kindly furnished copies of the topographic maps of the State Forest lands which have so far been prepared. These maps were of great service, especially because no other detailed maps of most of these mountain areas exist.

As practically all of this report is concerned with the raw material used for silica brick and with its manufacture, the other refractories will be disposed of before this larger subject is considered in detail.

GANISTER.

The term ganister has come to be used rather loosely in this country for almost all high-silica rocks which are used as refractories. It is applied to the raw materials used in manufacturing silica brick as well as to a clay-bonded sand or crushed quartzite

used for furnace linings. The term was first used in England for a sandstone with just enough clay to make a good bond but not enough to lower the refractoriness too much for use. In the standard works on metallurgy the word ganister is now commonly used to denote a mixture, natural or artificial, of crushed quartzite and clay which can be used in lining steel and copper converters. This lining is applied as a plaster or rammed in between a shell and the metal lining of the furnace. The clay should be of a refractory type and comprise usually 10 to 15 per cent of the mixture. Crushed quartzite, disintegrated soft sandstone, and natural sand may be used in building up bottoms in copper furnaces but the material is fritted or cemented with slag.

In Pennsylvania, ganister from the Tuscarora and Chickies quartzites is mined for sale either in the lump or crushed form or for use in making silica brick. Some other formations have been used to a smaller extent. An example is the Pottsville sandstone or quartz conglomerate, from the quarry of L. J. Bour Refractories Company, Scranton. Near Valley Forge the Chickies quartzite is quarried and used in lining the iron furnaces of Schuylkill Valley. Tuscarora quartzite is shipped from many points for use in the manufacture of refractories. Most of it is shipped as small blocks as they come from the quarry and these are crushed at the steel plants and mixed with clay. In electric furnaces much ground ganister is used without addition of clay. The rock shipped averages from 95 to 97 per cent silica, around 1 per cent alumina, and from 0.75 to 2 per cent iron oxide.

Fire clay is sometimes added to the crushed rock to increase the plasticity.

SILICA CEMENT.

A number of the silica brick companies make a silica cement by grinding silica brick bats with a refractory clay and, in some cases, crushed quartzite is added. Silica cement is made at the Harbison-Walker plant at Mount Union, the United States Refractories at Mount Union, and the General Refractories at Sproul. Some cement is reported from the L. J. Bour Refractories Company of Scranton. The proportions of clay to ground brick vary greatly, depending upon the particular use to which the cement is to be put. Some of the proportions mentioned are as follows:—clay 25 per cent, brick bats 75 per cent; clay 20 per cent, brick bats 80 per cent; clay 25 per cent, brick bats 25 per cent, and crushed quartzite 50 per cent. The last is used mainly in coke ovens; it gives a little more expan-

sion than if the raw quartzite were not included. The United States Refractories Corporation uses a nearly white clay obtained from the Oriskany sandstone near Shirleysburg, Huntingdon County, and the Harbison-Walker Refractories Company has used a somewhat similar white siliceous clay from the Gatesburg sandstone at Oreminea, Blair County. The cement is ground either in a dry pan or in a Sturtevant ring roller mill. It is used for plastering joints in coke ovens, furnaces, and stoves, and as mortar where high temperatures exist.

MICA SCHIST.

Certain portions of the Chickies formation from the Upper Cambrian in southeastern Pennsylvania contain sufficient mica to justify the name mica schist instead of quartzite, the name of the rock which comprises the greater part of this formation. Some bands of this mica schist make a very good refractory because the rock will stand high temperatures, is durable, and easily trimmed. The rock is really a highly metamorphosed quartzite with practically all the aluminous impurities altered to muscovite, the colorless mica. Where the mica is not too abundant the fusibility of the rock is practically that of quartz because even though the mica fuses at a comparatively low temperature it simply glazes the surface of the rock and exerts very little influence on the fusibility of the rock as a whole. A fusion test on the rock showed that even thin edges on fragments did not fuse at 1700°C. The melting point of cristobalite, the highest temperature form of silica, is 1710°C., or by the cone method of determining fusion points, 1785°-1790°C.

The mica schist which is preferred for refractory purposes splits readily into slabs and is soft enough to be broken in the hand. The softness permits it to be trimmed readily and, if necessary, to be cut with a tool to fit a space in a furnace. The soft refractory schist which occurs in bands in the Chickies formation is usually quarried in conjunction with other rock used for building purposes. The harder stone is used for foundations, walls and concrete work, and some of the smaller pieces have been ground for use in pebble-dash. The mica schist was selling in the summer of 1921 for $2.00 to $3.00 per ton and during the war it sold as high as $4.50.

Several quarries in the vicinity of Edge Hill, about three miles northeast of Germantown, are producing mica schist for refractory purposes. These quarries are along a ridge close to the road between Laverock and Edge Hill. The strata, in general, strike N 60° E and dip S. E. 70°. The following is a description of the quarries beginning with the one nearest Laverock.

Edge Hill Silica Rock Company. A quarry operated by the Edge Hill Silica Rock Company of Edge Hill and opened about 1913, is producing rock said to be used for lining lime kilns, Bessemer converters, and large cupolas. It averages about 85 per cent silica, and is sold under the trade name "Mica schist." The rock selected must be free from the veins of quartz which have specular hematite as a common accompaniment and which occur in many places in the Chickies formation. The rock is shipped in "one-man" and "two-man" sizes as it comes from the quarry. Some of the rock must be drilled and blasted but much of it can be pried loose with a bar. This quarry is 300 feet long and has a maximum depth of 60 feet. There is a very large amount of waste as about two tons of dirt are removed for every ton of good rock secured.

Edge Hill Stone and Construction Company. Along the same ridge as the quarry of the Edge Hill Silica Rock Company and 500 feet northeast is the quarry of the Edge Hill Stone and Construction Company of Edge Hill. This quarry is 230 feet long and exposes about 300 feet of the Chickies formation. The lowest 20 feet is a hard quartzite with relatively little mica, and above this is 75 feet of a hard schist which is used for construction work. The remainder of the formation consists of soft crumbling bands of mica schist interbedded with good refractory schist. These softer bands vary from a few inches to several feet in width. The quarry has a maximum depth of 55 feet and an overburden up to 15 feet thick. It is estimated that 3 tons of waste are removed for each ton of good rock secured. This quarry was opened in 1913. The company is said to control 8 acres of this land.

Luther Clayton quarry. The quarry owned by Luther Clayton lies 875 feet farther northeast along the road. At the time of the writer's visit, the rock from this quarry was being used entirely for building purposes although there is considerable mica schist available. The upper 140 feet of the formation exposed is very soft schist and in places the rock is decomposed to a white sand. The formation is, in most respects, similar to that in the adjacent quarry already described. The Clayton quarry is large, being 500 feet long and 75 feet in maximum depth. The overburden is 5 to 15 feet thick.

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Other quarries. Following along the same ridge through Edge Hill other quarries are found, but very little schist has been quarried from them for refractory purposes. A number of quarries produce building stone and one owned by Kenyon Brothers has produced considerable ganister. This quarry is in Edge Hill just east of the main road through the town. The rock which is very largely

quartzite, is crushed and screened for ganister. Some of it is used for chicken grit. Small quantities of mica schist might be obtained from several of these quarries.

Southwest from these quarries, in the direction of Laverock, there is some mica schist but good exposures are so few that it is impossible, without excavating, to decide whether there are other good quarry sites. So much of the land in the area is valuable residence property that quarries cannot be opened economically where good schist might be secured at several points on the ridge just southwest of the quarry of the Edge Hill Silica Rock Company.

SILICA BRICK.

Definition.

The term silica brick is used in this report for a high grade refractory consisting essentially of silica, bonded with lime. A number of terms such as "quartzite brick", "ganister brick", "dinas brick", and "sand-lime brick" are in use, which are sometimes confused. "Quartzite brick" is the term used in America for a brick made of ground ganister bonded with clay. Such brick contains about 72 per cent and upward of silica. This type would correspond to the "ganister brick" of the British Isles and to the German "dinas brick". It is not used a great deal in America. The original "dinas brick" was made from a sandstone in the Vale of Neath, Wales, by Weston Young who mixed limestone with the crushed sandstone and burned the mixture until it was satisfactorily bonded. From these early experiments developed the lime-bonded silica brick of the present day although the term "dinas" is seldom used in America. It is used in Germany and in Great Britain, but the German dinas is more like the quartzite brick of America and the ganister brick of England than like the American silica brick. The term ganister brick is not often used in the United States. Sand-lime brick is not used as a refractory, but large quantities are used in Europe and to an increasing extent in this country for building purposes. It contains about 6 per cent of lime as a bond mixed with sand or crushed sandstone and it is bonded in steam under pressure.

Uses of silica brick.

Silica brick has an extensive use in metallurgical industries because of its high fusing point and its expansion on heating, but particularly on account of its rigidity and strength at high temperatures. It is used in copper reverberatory furnaces, in copper refining furnaces, in acid converters in the manufacture of steel, in coke ovens, in the roofs of tanks and pot furnaces in glass manu-

facture, in vertical lime kilns, and in gas retorts. In most types of coke ovens silica brick is used for the canals and ovens. The structure above the floor, except for the facings, is of this brick and in some of the regenerative types of ovens even that below the floor is made of it also. In the steel plants such furnaces as the Martin type have the roofs and floor of silica brick.

Chemical properties of raw materials for silica brick.

The production of satisfactory silica brick requires a rock containing over 96 per cent silica, less than 2 per cent iron oxide, less than 1.5 per cent alumina, and not more than 0.5 per cent alkalies. The lime and magnesia should preferably not exceed 0.5 per cent for each of these oxides since they nearly always indicate the presence of carbonates. One of the constituents mentioned above may be slightly higher if the others are low, but the combined alumina and iron oxides should not exceed 2.75 per cent and the total of the basic oxides 3 per cent. On the other hand, as will be pointed out later, the best results are not obtained if the percentage of these oxides drops below 1.5 per cent since they aid in the transformation of the silica, but particularly in the development of a good bond.

The following analyses indicate the composition of typical high grade quartzite used in Pennsylvania, Wisconsin, and Alabama. Additional analyses of quartzite from Pennsylvania are found in a table in another part of this article.

Analyses of quartzites used in manufacture of silica brick[2]

	I	II	III	IV	V	VI
SiO_2	97.80	97.70	98.22	98.59	98.31	96.73
Al_2O_3	0.90	0.96	1.08	0.53	0.72	1.39
Fe_2O_3	0.85	0.81	0.23	0.23	0.18	0.48
CaO	0.10	0.05	0.00	0.03	0.22	0.19
Mgo	0.15	0.30	0.01	0.02		
Alkalies	0.40	0.31			0.14	0.20
Loss on ignition			0.46	0.60	0.35	0.50
Total	100.20	100.12	100.00	100.00	99.92	99.49

No. I, Pennsylvania, Tuscarora (Medina) quartzite: II, Alabama quartzite: III and IV, Baraboo, Wisconsin quartzite: V and VI, English dinas from Perth.

From a list of analyses given by Havard[3] the good grade Baraboo and Devils Lake quartzites of Wisconsin vary in per cent as follows:

[2] I and II, Soaver, Kenneth. Manufacture and tests of silica brick for the by-product coke oven: Trans. Amer. Inst. Min. & Met. Eng. Vol. LIII, p. 125, 1915: III and IV, Analys s furnished by Hotchkiss, W. O., State Geologist of Wisconsin; V and VI, Sexton, A. Humbolt. Fuel and Refractory Materials: Blackie & Sons, Ltd., p. 331, 1909.

[3] Havard, F. T. Refractories and Furnaces: McGraw-Hill Book Co. 1912.

Analyses of Wisconsin quartzites.

SiO_2	97.93 to 99.04
Al_2O_3	0.35 to 1.27
Fe_2O_3	0.65 to 1.69
CaO	0.01 to 0.03
MgO	0.01 to 0.03
Loss on ignition	0.28 to 0.70

Some of this rock is described as quite red but the iron in it is so thoroughly oxidized and so evenly distributed that the percentage is much less than appears from the color. It should be borne in mind that chemical purity, while important, is not the only factor, as mechanical strength and behavior in burning are of the greatest importance. Pure vein quartz, chalcedony, or opal do not bond well but decrepitate in firing, and a quartzite with over 98.5 per cent of silica does not bond well (unless mixed with other rock) but forms a weak and friable brick.

SOURCE OF RAW MATERIALS FOR SILICA BRICK AND GANISTER.

The rocks used in Pennsylvania as raw materials in the manufacture of silica brick are quartzites and dense, quartz conglomerates. Of the material manufactured it is estimated that about 94 per cent comes from one formation, the Tuscarora (Medina) quartzite. Practically all of the remaining 6 per cent comes from the Chickies quartzite. A small quantity of brick has been made in the past from the Homewood sandstone of the Pottsville formation and there is a small production of ganister rock from the Pottsville at Scranton. Where this formation is suitable for ganister it is dense silica sandstone or fine-grained quartz conglomerate almost free from impurities. There are few localities where the Homewood sandstone is pure enough and at the same time sufficiently well cemented with silica to make a good ganister rock.

Tuscarora Formation.

This formation receives its name from Tuscarora Mountain, in Pennsylvania, which is composed of this rock. It has generally been known in the older geological reports as the White Medina. It is one of the lower members of the Silurian system and by some geologists is regarded as the basal member of this system. Throughout Pennsylvania the formation is non-fossiliferous with the single exception of a peculiar fossil known as *Arthrophycus alleghcniensis*. This fossil has been variously regarded as worm burrows and as a plant. The writer strongly favors the latter view. It is abundant

in the shaly layers in the formation in most of its outcrops throughout the State and is a very characteristic horizon-marker. It occurs in some places in large slabs, as illustrated on page 58. This formation is evidently a beach and shallow water deposit made in a transgressing sea which covered all the central and south central portions of Pennsylvania following a period of combined terrestrial and delta deposition. This period of deposition is represented by the red Juniata shale and sandstone and the gray and brown Oswego conglomerate and sandstone which underlie the Tuscarora almost everywhere it outcrops in the State.

The Tuscarora formation is the greatest mountain-forming rock in central and south central Pennsylvania because of its resistant nature. It forms long, narrow, even topped ridges, topographic features characteristic of this portion of the great Appalachian Province. These ridges are in nearly all localities associated with other ridges composed of the Oswego sandstone and conglomerate and separated from those of the Tuscarora by rather deep and narrow valleys eroded in the less resistant red shales and sandstone of the Juniata formation. The ridge of Oswego and the characteristic intervening valley are lacking in the eastern portion of the State along Blue Ridge because the Oswego and Juniata formations are absent or so thin as to have little influence on the topography.

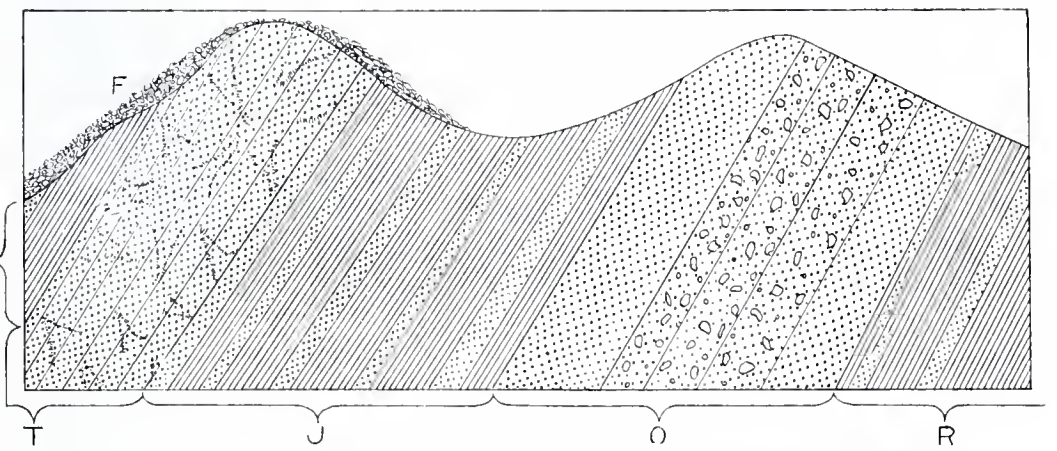


Figure 3. Structure section illustrating typical topographic relations of Clinton, Tuscarora, Juniata, and Oswego formations of Central Pennsylvania.

C-Clinton, etc.; T-Tuscarora quartzite; J-Juniata red sandstone and shale; O-Oswego sandstone and shale; F-Floe rock.

Distribution. The distribution of the exposures of the Tuscarora quartzite is indicated by the accompanying maps Figs. 1 and 2. The Tuscarora formation extends as a series of roughly parallel ridges from Susquehanna River, near Williamsport on the northeast, to and across the Maryland-Pennsylvania border, near Cumberland, Md.

The Bald Eagle Ridge begins southeast of Williamsport, near Muncy and, although bent in many places and known by different names, continues as Brush, Canoe, Lock, Dunning, and Evitts mountains to the southern State line. It divides near the State line and as Martin Mountain, then Tussey Mountain, runs northeast-by-north as a great hog-back ridge into the Seven Mountains near the center of the State. Here it joins a veritable maze of ridges. From the Seven Mountains the ridge made by the Tuscarora, with many twists and turns and known by many local names, including the White Deer Mountain, runs northeastward to join Bald Eagle Ridge at Muncy. An important offshoot from the Seven Mountains is Standing Stone Mountain which joins Jacks Mountain, the latter continuing south as a double ridge to Saltillo. Jacks Mountain carries the important quartzite deposits at Mount Union and Three Springs.

There are several important isolated ridges surrounding pitching anticlines and synclines on which the quartzite forms a protecting rim. One of these is the anticlinal extending from near Bedford southward to the State line near Cumberland, Md. and including Buffalo Mountain and Wills Mountain. In the center of this structure the Oswego and Juniata formations are brought to light. The Nittany Mountain synclinal in Centre and Clinton counties is an irregular trough-shaped structure with the Clinton formation in the center and the ridge of Oswego conglomerate and sandstone surrounding the Tuscarora on the outside. Shade Mountain is made up of a group of ridges surrounding oval-shaped, pitching anticlines in which the Juniata, Oswego and Reedsville formations come to the surface. This mountain is divided at the Lewistown Narrows by a narrow syncline containing Clinton shales. Juniata River flows through this gap a short distance below Lewistown. Along the banks of the river in the Narrows are important quartzite deposits. Licking Creek flows along another narrow syncline which separates two large pitching anticlines surrounded by Tuscarora quartzite.

Tuscarora Mountain which noses out to the eastward at Juniata River near Millerstown, extends as a high, narrow ridge southeastward to a point near Honey Grove station where the southwestern end of the anticline also pitches from view. Liberty Valley separates this portion of Tuscarora Mountain from the remainder which begins on the southeast side of this small valley and extends to the vicinity of McConnellsburg where it joins Cove Mountain and where a series of ridges is crossed by the Lincoln Highway. Tuscarora Mountain extends southward close to the border of the State and then sends a short hook northward. Cove Mountain, which is separated from the main ridge of Tuscarora by a large fault, runs

slightly south of the State line and then turns northward, ending near the line in a knob known as Two Top Mountain. An offshoot of Tuscarora Mountain starting near Burnt Cabins ends just north of McConnellsburg. The long and prominent Blue Mountain begins near Fort Loudon, where the Lincoln Highway descends from Cove Mountain, and runs as an unbroken ridge, except for deep gaps cut by the Susquehanna, Schuylkill, and Lehigh rivers, to Delaware Water Gap at the State border. The typical Tuscarora quartzite merges into the Shawangunk grit in the eastern part of the State. Blue Mountain branches at its southwestern end around the syncline to form Kittatinny Mountain which merges into a complex series of ridges south of New Germantown and from which Conococheague Hill branches to join Tuscarora Mountain on the border of Liberty Valley.

One rather striking feature of the ridges of Tuscarora quartzite in the southwestern portion of this large area is the absence of the second ridge composed of the Oswego formation which is so characteristic of the areas farther north and west. This ridge is not found along the southern part of Tuscarora Mountain, along Cove Mountain, or along the southern part of Blue Mountain in places where it should appear if the Oswego formation were present.

The highest altitude on the mountains composed of the Tuscarora formation is 2541 feet, as indicated by a bench mark on Tussey Mountain, just southeast of Woodbury, Bedford County. There are many points more than 2300 feet above sea level.

Structural features. The structure of the Tuscarora formation on the whole is comparatively simple, although dips range from almost zero to vertical and in places the beds are overturned. This heavy, competent formation has suffered considerable distortion in many places but the tendency has been for it to maintain a relatively simple structure while other, less competent, formations have crumpled into complex folds. Being a comparatively brittle rock, it has fractured readily and has been faulted in a number of localities. The largest faults observed are the following: the fault running parallel to Tuscarora Mountain and separating it from Cove Mountain ridge near the Fulton-Franklin county boundary; a transverse fault with a 700-foot offset, cutting Tuscarora Mountain where the main road crosses it a short distance below Concord, Franklin County; a large fault offsetting Tussey Mountain about two miles east of Waterside, Bedford County; a thrust fault with displacement of 550 feet along the Little Juniata River between Barree and Spruce Creek. This fault apparently joins a large fault which runs nearly parallel to Tussey Mountain for a long distance and entirely cuts out the front ridge along the face of Short Moun-

tain, where the Federal Refractories Company has its quarries. The Little Juniata follows this latter fault where it makes the big bend eastward from the Pennsylvania Railroad tunnel just below the village of Spruce Creek. This fault appears to extend to a point near Williamsburg. The Tuscarora is completely offset by a large fault which cuts Stone Mountain on the road between Belleville, in the Kishacoquillas Valley, and Greenwood Furnace; about 10 miles northeast from the last fault Slate Ridge in the Seven Mountains is offset about 1100 feet; a fault in Hubler Gap separates Rudy Mountain from Kocher Mountain, an offset from Tussey, south of Shingletown, with a displacement of 600 feet; an important fault separates Canoe Mountain from Lock Mountain at Point View where the Frankstown branch of the Juniata cuts through the mountain, about three miles northwest of Williamsburg; there is apparently a small displacement in Tyrone Gap; and at Vail the next station northeast of Tyrone on the Bald Eagle Valley Railroad, Bald Eagle Mountain is displaced about 300 feet. A fault occurs near Port Clinton on Schuylkill river. Very few of the faults mentioned have had any important influence on quarrying the Tuscarora formation.

Thickness. The Tuscarora is remarkably uniform in thickness and probably averages about 400 feet. It is difficult to find both bottom and top of the formation exposed and only in a few gaps and quarries can an accurate measurement of thickness be secured. The formation is thinnest at Duboistown near Williamsport, where it is only 200 feet. In Lamar Gap not far to the westward it averages about 500 feet and in the Bellefonte Gap it is 495 feet thick. In a quarry in McKee Gap, near East Freedom, it is 345 feet and in the gap through Tussey Mountain at Water Street it reaches about 350 feet. Farther down the Juniata where the river cuts Jacks Mountain above Mount Union the thickness is 520 feet. Where the Lincoln Highway passes through Evitts Mountain at Cliff, a short distance below Bedford, the formation is 380 feet and near Buffalo Mills south of Bedford 400 feet thick. In Tussey Mountain northwest of Saxton the thickness is 500 feet and at Paddy Mountain, on the Lewisburg and Tyrone division of the Pennsylvania Railroad, it is 275 feet.

Following Tuscarora, Cove, and Blue Mountains northeastward from the southern border of the State it is found that the formation is about 275 feet thick in the Mercersburg district, 250 feet near Roxbury, 300 feet in the Harrisburg Gap, 250 feet at Port Clinton, where the Schuylkill River cuts the ridge, 500 feet in the Lehigh Gap, and around 1200 feet in the Delaware Water Gap. It is thus seen that the thinnest and the thickest portions of the formation occur in the eastern portion of the area of outcrop and the great thickness

around Delaware Water Gap can be explained only by assuming that this area was nearer the source of the sediments. Although the maximum and minimum differ greatly the thickness is remarkably uniform over wide areas.

Rock floes. One of the most characteristic features of the Tuscarora formation is the great areas of white, broken rock or talus which lie below its outcrop in the mountains (Pl. I). These areas of broken rock creeping down the mountain sides at an im-

PLATE I.—Large rock floe along Juniata River, in gap at Water Street, Huntingdon County. Here the Tuscaroro quartzite is ferruginous and mixed with talus from the Juniata formation.

perceptible rate are generally known as rock floes. Their thickness varies from a foot or so up to 35 feet. The very thick spots are in depressions at the foot of the mountain or in ravines along the mountain faces. A floe less than 3 feet thick is of little economic importance as a rule because the large proportion of soil and vegetal matter mixed with the quartzite makes it unprofitable to handle. It is very difficult to estimate accurately the thickness of the floes and to judge the tonnage which they contain. Quartzite in the solid form weighs about 170 pounds per cubic foot and when broken to egg size, about 90 to 100 pounds per cubic foot. It is also difficult to determine the percentage of rock suitable for silica brick or ganister because of the gradation of poor rock into high grade rock in some localities. In testing the quality of the floe it is customary to collect fragments from the mass so as to secure a sample which will be representative of a certain percentage of the whole floe and in that way decide whether it is of sufficiently high grade to warrant

quarrying. This method was followed in selecting the samples, the tests of which are recorded below. Further, it was found difficult in many localities to determine from the floe the true nature of the solid formation underlying it because in some places the talus comes mostly from certain bands in the formation and in other places many fragments from adjacent rock formations are included in the floe.

The floes are comparatively free from fragments of the Clinton formation, which is younger than the Tuscarora and which lies stratigraphically, but not topographically above it, except where these formations occur in overturned folds. The absence of Clinton fragments is largely due to the ease with which the soft sandstone and shale of this formation weather away, keeping its upper limit well down the mountain side. In a few places where it rides high up on the mountain calcium carbonate and iron salts dissolved from the Clinton formation may be carried down into the Tuscarora quartzite and deposited in cracks and other openings. A few cases of high lime reported by brick makers seem to be assignable to this source because the Clinton contains much calcareous shale and some limestone.

The Juniata formation is much more likely than the Clinton to furnish impure fragments to the floe because certain layers in the Juniata consist of quite hard and resistant, ferruginous sandstone. These may resist weathering in some places better than the Tuscarora quartzite and they therefore outcrop in the mountain top and add their quota of fragments to the great mass of broken rock which slides down the mountain side.

The floes are made up of blocks ranging up to several feet in diameter, with a weight of several tons. The average size of the fragments in one floe may differ greatly from those in another. Some floes consist largely of fragments which can be handled by one man; in others over 80 per cent of the pieces must be broken before a man can lift them (PI. II). In some floes nearly all the fragments are sharply angular and in others they are roughly rounded. There is a tendency for the sharply angular fragments to break up into comparatively small blocks because they are harder and more brittle than those of rounded outlines. These features have a bearing on the quality of the quartzite for silica brick because the fact that the fragments weather with rounded outlines indicates that they are less completely cemented and are more friable. Friability is a quality which is undesirable in a quartzite for ganister or silica brick although very desirable in a glass sand.

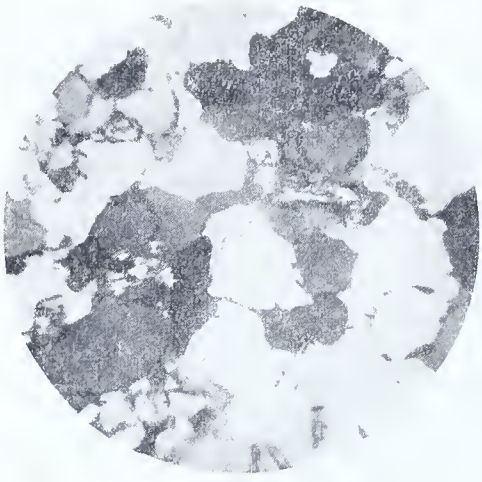
The most striking floes are those south of Hollidaysburg, around Point View, near Water Street, at Port Matilda, below Spruce Creek, near Mount Union and in the Lewistown Narrows. There are many other areas of importance and an effort has been made to show the location of the floes on the accompanying maps.

PLATE II.—Haws Refractories Company quarry, at Hawstone, Lewistown Narrows, utilizing large blocks of talus which have crept down over the bed of smaller blocks.

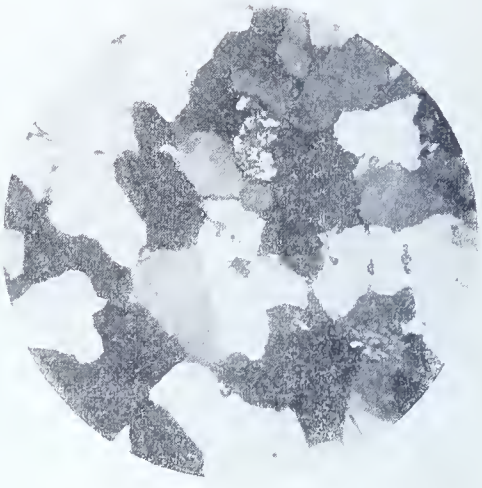
The large floes are much in demand because the broken weathered rock is more cheaply quarried and is a little higher grade than the solid rock underlying it. Experience has shown that there are many local peculiarities in the quartzite which must be treated in a particular way, and the brick-maker finds that if he changes his source of supply he may also have to change his methods of burning.

Petrographic characters. This rock consists almost entirely of grains of quartz which, in the best types of rock, have been enlarged by the addition of silica to the original sand grains. This added silica maintains the same crystallographic orientation as the silica in the original grain. The relation between the original grain and the added silica is well illustrated in the accompanying photomicrograph (Pl. III, A). The original rounded grains are outlined by a film of iron oxide. In addition to the quartz there are in some of the thin sections grains of chert and of shale (Pl. III, B). In some there are additions of chert or other types of cryptocrystalline silica. There are also small grains of tourmaline with characteristic pleochroism, grains of zircon, rutile and titanite. A very striking feature of the quartz grains is a sort of striated appearance due to

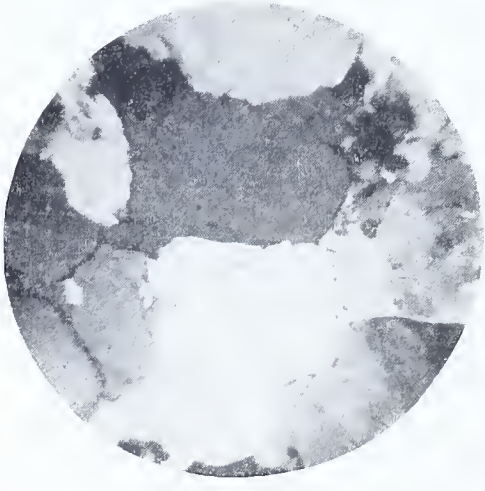
PLATE III



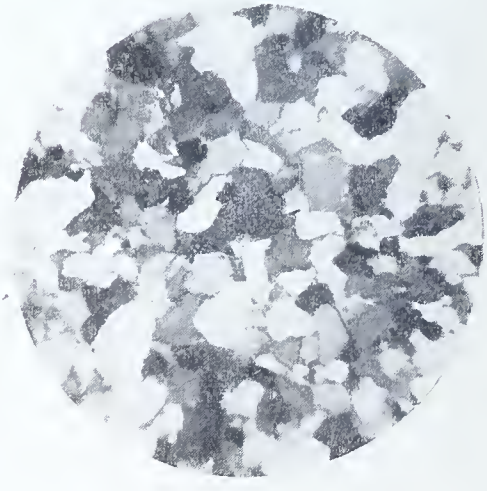
A. Photomicrograph of impure Tuscarora quartzite showing the orignal sand grains (outlined by films of iron oxide) of the sandstone from which the quartzite was derived. (X60)



B. Photomicrograph of Tuscarora quartzite showing fragments of shale.



C. Photomicrograph of coarse grained Tuscarora quartzite showing typical lines of mineral inclusions giving the specimen a straited appearance (X60)



D. Photomicrograph of a very fine grained, well cemented type of Tuscarora quartzite. (X60)

numerous inclusions of mineral matter arranged in roughly parallel lines (Pl. III, C). This arrangement indicates that the quartz grains have been derived from highly squeezed and metamorphosed rocks. The presence of the zircon, tourmaline and titanite, which are characteristic accessory minerals in igneous rocks, suggests that the source of the quartz for the Tuscarora formation is to be found in the highly metamorphosed pre-Cambrian igneous rocks which were exposed along the eastern border of the continent during Silurian time. One peculiarity in the occurrence of the inclusions in some of these quartz grains is that they extend beyond the border of the original sand grain into the surrounding silica. This silica surrounding the original grain has apparently been deposited when the quartzite was formed. Similar inclusions are found in some of the sand grains which form the nuclei of the siliceous oolites occurring in the Upper Cambrian in central Pennsylvania. It is possible that where the grains show this feature they represent fragments of a previously existing quartzite which has been broken up to form a new sandstone or the lines may be due to shearing in the existing rock. The degree of cementation in the quartzite varies considerably. The photomicrographs show the differences between a well cemented quartzite (Pl. III, D) and a rock with a ferruginous cement (Pl. III, A) and also the relative size of the quartz grains. The grains were found to average 0.28 mm. in diameter for 26 sections of average quartzite examined. The minimum average for each of the 26 sections was 0.15 mm. and the maximum average 0.4 mm. The greatest variations in size for the 26 slides ran from about 0.02 mm. in diameter to 1.5 mm. and the greatest variation in an individual slide was 0.02 mm. to 0.8 mm.

Some parts of the formation contain pebbles of quartz many times the size of any of the grains mentioned here. On the whole the coarser portions of the rock are more friable and do not furnish as good a quality of quartzite for silica brick as the finer portions. Considering the State in a broad way the Tuscarora formation is coarser grained in the southern and eastern parts of its outcropping area, than elsewhere. In the ridges between Bedford and the Pennsylvania-Maryland line the rock is of high purity but it is coarser in grain and more friable than in the ridges north of the Lincoln Highway. Further, the formation in the region northeast and east of the road from Bellefonte to Lewistown does not average as pure a quartzite as in the area lying between these two roads, the William Penn and Lincoln highways, and much of it is rather friable.

Analyses and tests. An attempt was made to determine the quality of the Tuscarora formation by collecting a large number of samples from different parts of the State and testing these for their

physical and chemical properties. The results of these tests are set forth in the following table. The fusibility of the various samples was determined by Mr. Taylor in the following manner: The crushed quartzite was mixed with a 5 per cent dextrine solution and 1.75 per cent of lime by weight. Cones were made from this mixture and fired in an electric furnace, the temperature being recorded by means of Seger cones checked by an optical pyrometer. The figures obtained must be regarded very largely as relative rather than absolute from the practical standpoint since the conditions are not just such as obtained in a kiln. They, however, give a very fair idea of the comparative worth of the quartzite in different parts of the State. This table should be consulted in conjunction with the accompanying maps (Figs. 2 and 3) to get a proper conception of the possibilities of the various areas. The figures on the maps indicate our ideas of the percentage of the rock in the various areas which could be used in the manufacture of silica brick. Two determinations for fusibility were made on each sample. The first was made on a sample pulverized to about the same grain size as that in the regular grind for brick. It lacked the large fragments which occur in the mud from a wet pan because such large fragments of quartz could not be handled in making cones. The second determination was made on the sample which passed a 150-mesh screen. This was in order to determine the relation between fusibility and the size of grain.

The estimated percentage of the mass which each sample represents appears in the table.

Analyses and tests on samples of Tuscarora quartzite.

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	Total per-cent	Fusion point degrees C.		Character of deposit	Percent of deposit repre-sented
						Coarser material	Through 150 mesh		
2	97.34	0.96	1.25	a	99.55	1,735	1,735	Floe	70
3	97.30	0.90	1.39	a	99.59	1,730	1,729	Floe	70
4	97.11	0.98	1.37	a	99.46	1,729	1,727	Floe	40
5	97.10	0.99	1.51	a	99.60	1,711	1,712	Floe	60
7	96.98	0.92	1.78	a	99.68	1,708	1,710	Floe	45
8	97.50	0.90	1.45	a	99.85	1,732	1,730	Floe	40
9	97.21	1.04	1.45	a	99.70	1,734	1,730	Floe	40
10	97.01	a	a	a	97.01	1,726	1,720	Ledge	50
11	97.17	1.07	1.48	a	99.72	1,714	1,710	Floe	50
12	97.20	1.02	1.44	a	99.66	1,720	1,720	Floe	30
13	97.98	0.90	0.70	0.10	99.68	1,768	1,765	Floe	75
14	98.09	0.87	0.79	0.11	99.79	1,765	1,755	Floe	85
15	98.02	0.93	0.73	0.12	99.80	1,760	1,757	Ledge	65
16	97.82	0.90	0.83	0.10	99.65	1,760	1,754	Ledge	75
17	97.35	0.99	1.34	0.10	99.78	1,727	1,729	Floe	60
18	97.45	0.97	1.26	0.09	99.77	1,751	1,750	Floe	40
19	97.24	1.04	1.36	0.13	99.77	1,728	1,730	Floe	75

a Not determined.

Analyses and tests on samples of Tuscarora quartzite.—Continued.

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	Total per-cent	Fusion point degrees C.		Character of deposit	Percent of deposit repre-sented
						Coarser material	Through 150 mesh		
20	97.46	1.05	1.07	0.11	99.69	1,739	1,740	Floe	70
21	97.60	1.05	1.09	0.10	99.84	1,739	1,734	Floe	75
22	97.35	0.85	1.08	0.11	99.39	1,750	1,750	Floe	70
23	97.21	0.89	0.18	0.11	99.39	1,743	1,742	Ledge & Floe	85
24	97.81	0.90	0.88	0.09	99.68	1,761	1,760	Floe	65
25	98.06	0.81	0.70	0.09	99.66	1,783	1,778	Floe	60
26	98.04	0.89	0.80	0.14	99.87	1,761	1,760	Floe	50
27	97.65	0.99	1.04	0.11	99.79	1,760	1,760	Ledge	80
28	97.50	0.98	1.22	0.10	99.80	1,737	1,722	Ledge	75
29	97.35	0.95	0.92	0.14	99.36	1,750	1,740	Ledge	85
30	97.40	0.98	1.17	0.14	99.69	1,725	1,725	Ledge	85
31	97.56	0.94	1.04	0.10	99.64	1,738	1,740	Ledge	85
32	97.82	0.85	0.90	0.10	99.67	1,746	1,745	Floe	85
33	97.82	0.97	0.94	0.16	99.83	1,746	1,744	Floe	65
34	98.10	0.79	0.81	0.11	99.81	1,772	1,764	Floe	75
35	97.76	0.89	1.04	0.10	99.79	1,755	1,737	Ledge	80
36	97.66	0.92	1.07	0.11	99.76	1,740	1,740	Floe	80
37	98.06	0.84	0.76	0.12	99.78	1,771	1,763	Floe	80
38	97.70	0.82	1.01	0.12	99.65	1,763	1,746	Ledge	86
39	98.11	0.85	0.80	0.09	99.85	1,772	1,760	Ledge	70
40	97.82	0.84	0.94	0.12	99.72	1,746	1,745	Floe	75
41	98.08	0.87	0.79	0.10	99.82	1,773	1,764	Ledge	65
42	97.95	0.88	0.80	0.10	99.73	1,753	1,740	Floe	75
43	97.50	0.93	1.12	0.10	99.66	1,727	1,725	Ledge	75
44	98.10	0.80	0.80	0.10	99.80	1,759	1,758	Floe	75
45	98.96	0.33	0.50	0.05	99.84	1,748	1,745	Ledge	
46	97.70	0.91	1.00	0.13	99.74	1,766	1,736	Ledge	65
48	97.10	0.90	1.32	0.10	99.42	1,728	1,725	Floe	50
47	97.30	1.14	1.26	0.10	99.80	1,737	1,735	Floe	40
49	97.50	0.94	1.12	0.12	99.68	1,737	1,735	Floe	60
50	98.04	0.86	0.83	0.10	99.83	1,750	1,745	Floe	40
51	97.64	0.95	1.11	0.10	99.80	1,750	1,735	Floe	50
52	97.88	0.93	0.91	0.13	99.85	1,750	1,739	Ledge & Floe	45
53	97.76	0.91	1.00	0.10	99.77	1,760	1,750	Ledge	80
54	97.80	0.90	0.97	0.10	99.77	1,762	1,745	Floe	50
55	97.82	0.82	0.95	0.10	99.69	1,751	1,748	Floe	45
57	97.90	0.90	0.76	0.13	99.69	1,770	1,755	Ledge	45
61	98.10	0.78	0.79	0.09	99.76	1,786	1,775	Floe	85
62	98.10	0.80	0.67	0.11	99.68	1,786	1,765	Floe	85
65	97.94	0.83	0.86	0.09	99.72	1,762	1,737	Floe	50

Number and source of samples.

2. Clinton County, east side of Mill Hall Gap, Bald Eagle Ridge.
   From large floe ½ mile long, 600 feet wide, and about 12 feet thick.
3. Clinton County, east slope of Youngdale Gap, Bald Eagle Ridge.
   From large floe 15-20 feet thick.
4. Clinton County, east side of Lamar Gap, Bald Eagle Ridge.
   Rock comparatively soft and high in iron.
5. Clinton County, southern ridge of Tuscarora in Lamar Gap.
   Coarse talus, rather high in iron.
7. Centre County, 6½ miles east of Livonia, Brush Valley.
   Thin floe, average about 3 feet.
8. Centre County, south side of Lewisburg Narrows, 3 miles east of Woodward.
   Talus coarse grained and friable. Large floes, average 10 feet in depth.
9. Union County, Glen Iron Gap about 8 miles west of Mifflinburg.
   Large floes but rock soft, red, and contains shale pebbles.
10. Centre County, Bessemer Loam & Sand Company quarry, Paddy Mountain.
    From a quarry 154 feet long and 82 feet wide. Floes 6-10 feet thick.

11. Mifflin County, Tuscarora Ridge near Milroy on Bellefonte Road.
Floes thin, average 5 feet. Large blocks. Rock soft and friable.

12. Mifflin County, east side of Yeagertown Gap.
Floe thin, about 5 feet. Rock discolored.

13. Juniata County, Haws Refractories Company quarry at Hawstone near Lewistown.
Floes very large and, in places, thick.

14. Huntingdon County, Harbison-Walker Refractories Co. quarry Mount Union.
From rock pile, represents first-class rock used in plant.

15. Huntingdon County, Mount Union Refractories Co. quarry, Three Springs.
From a 25-foot band of high grade rock.

16. Huntingdon County, General Refractories Co. quarry, Neelytown.
Floe 8-10 feet thick and about 400 feet wide.

17. Centre County, east side Eagleville Gap, Bald Eagle Ridge.
Floe 800-1000 feet by 2-15 feet thick. Rock coarse and rather friable. Shale pebbles. Represents best 60 per cent grade.

18. Centre County, east side of gap above Howard, Bald Eagle Ridge.
Floe 800 by 700 feet in diameter, and 2-20 feet thick, average 8 feet. Rock high in iron in most places.

19. Centre County, east side of gap at Curtin, Bald Eagle Ridge.
Floe 500 by 600 feet by 2-10 feet thick, average 6 feet.

20. Centre County, east side of Milesburg Gap, Bald Eagle Ridge.
Floes extensive but comparatively thin.

21. Centre County, east side of gap above Unionville, Bald Eagle Ridge.
Floe of white dense quartzite 5-10 feet thick, and 200 by 300 feet.

22. Centre County, east slope of gap above Julian, Bald Eagle Ridge.
Floe about 10 feet thick and 800 by 400 feet. Much of rock spotted brown.

23. Centre County, rock used at Superior Brick plant, Port Matilda.
Represents the average rock from quarry.

24. Blair County, on Bald Eagle Ridge near Tipton.
From a large talus floe.

25. Blair County, east side of Altoona Gap, Brush Mountain.
Small but high grade floes.

26. Blair County, east side of Tyrone Gap, Bald Eagle Ridge.
Floe thin and most of rock colored by iron.

27. Huntingdon County, E. R. Baldridge Company quarry, near Barree.
From quarry 420 feet long, 2-60 feet high. Numerous clay seams.

28. Huntingdon County, General Refractories Co. quarry, Short Mountain near Spruce Creek.
Average rock from quarries.

29. Blair County, Kier Fire Brick Company quarry at Brookes Mills.
Average rock shipped.

30. Blair County, rock from J. L. Hartman Company's quarry.
Sample taken from cars at Sproul plant of General Refractories Company.

31. Blair County, Standard Refractories plant. Claysburg.
Average rock used.

32. Bedford County, Dunning Mountain between St. Clairsville and Brumbaugh.
Large floes in this vicinity. Rock pure but inclined to be friable.

33. Blair County, Loop Mountain, 2 miles from Roaring Springs.
From top of mountain. Average sample rock rather coarse grained.

34. Blair County, north slope Lock Mountain between Point View and Sissler.
Most of rock is dense and pure; some is "sandy."

35. Blair County, J. L. Hartman Company quarry, near Flowing Spring.
About 200 feet exposed. Much clay and overburden. Some rock very high grade.

36. Blair County, J. L. Hartman Company quarry on east side of river near Flowing Spring.
Most of talus has been stripped off.

37. Blair County, Harbison-Walker Company stripping near Goodman Station.
Large floes.

38. Bedford County, Tate's quarry at Cliffs, Evitts Mountain.
Rock coarse grained to crystalline and fine grained. Band 100 feet thick.

39. Bedford County, E. R. Baldridge Company quarry at Wolfsburg.
Part of rock coarse and "sandy." Part high grade.

40 .Bedford County, M. V. Brant's quarry at Buffalo Mills.
Rock varies from quartzite to small pebble conglomerate.

41. Bedford County, north side of gap at Sulphur Springs.
Part of rock excellent but much "sandy" material.

42. Bedford County, Leap Ganister Company quarry at Madley.
Rock pink to white, partly "sandy" but pure.

43. Bedford County, small abandoned quarry near Savage Refractories Company plant at Hyndman. Talus very "sandy" and soft.

44. Bedford County, quarry on Mount Dallas.
Floe originally 10-15 feet thick, and 400 by 350 feet.

45. Huntingdon County, Oriskany formation. Pennsylvania Glass Sand Company quarry at Mapleton.
A high grade glass sand.

46. Fulton County, 1 mile south of Webster Mills.
Formation thin but dense and well cemented.

47. Fulton County, Knobsville Gap, Scrub Ridge.
Rock soft and discolored, on whole.

48. Fulton County, Tuscarora Mountain on road between McConnellsburg and Mercersburg.
Rock "sandy," and small pebble conglomerate. Friable.

49. Franklin County, Cove Mountain south of Africa.
Floe thin and of little importance.

50. Franklin County, south slope of Franklin Furnace Gap.
Floes of considerable extent but most of rock is coarse grained and friable.

51. Franklin County, Jordan Knob.
About half of rock red to brown. Talus thin.

52. Franklin County, on road between Spring River and Roxbury.
Rock discolored and sandy.

53. Huntingdon County, gap in Tuscarora Mountain below Concord and 1½ miles from Blairs Mills.
From a band of solid rock 90 feet thick.

54. Perry County. Conococheague Hill north of New Germantown.
Large floes of good rock. Most of rock coarse and friable.

55. Juniata County, southwest side of Honey Grove Gap.
Much of the rock discolored and soft in this area.

57. Schuylkill County, Port Clinton, in gap on Schuylkill River.
From band 90 feet thick. Part of formation conglomerate. Bulk of formation unsuitable for brick.

61. Bedford County, gap in Tussey Mountain at Loysburg.
Large floe of dense high grade quartzite.

62. Huntingdon County, south side of Tussey Mountain south of Pennsylvania Furnace.
Large floe from 2 to 7 feet thick along north side of Diamond Valley.

65. Potter County, Pottsville sandstone. Galeton.
Source of talus, a bed about 50 feet thick, partly conglomerate and partly dense tough sandstone.

A striking feature of this table is the similarity in the analyses of the Tuscarora quartzite. At first glance it would appear that the rock from one locality could be used about as readily as that from another. However, if the results of the tests are not properly considered, a wrong impression will be gained. It would have been an easy matter to choose specimens in many of these localities which would have given tests in every way far below those recorded. The object in view in making the tests was to determine whether there is, in the various localities, any good silica rock and then to estimate what proportion of the ledge or floe is represented by the rock tested.

In general it may be said that the fusion point should not run below about 1740°C. (cone method) For many of the samples tested the figures are above that but the sample does not represent 100 per cent of the deposit. If the analysis shows high purity and the fusion point is high, then some of the inferior rock may be mixed with the high grade material without reducing the average below a proper standard. It has been concluded that unless about 70 per cent of the deposit comes up to the required standard in the table, there is not much use in endeavoring to work the deposit under present conditions. So much high grade rock is available and so many brick plants are already in operation that much material which in the future will be valuable cannot be satisfactorily used now. Much lower grade rock is used in foreign countries than that which has no sale at all in Pennsylvania today.

In some areas represented in this table, the rock is of high purity but soft or "sandy," as described by the brick men. It is not well cemented and crumbles too readily. This is a characteristic of much rock in the southern part of the State. It will be observed that in no case does a sample represent a full 100 per cent of the deposit because there is always a certain amount of waste rock, besides the actual overburden of dirt, which is not used in making good brick. This waste may be red rock or large boulders which are impure; or

in the ledge rock, clay seams or shaly bands may have to be eliminated. The figures in the table representing percentage of deposit do not always correspond with those on the accompanying map because those in the table refer to the samples and those on the map represent our estimate of rock which might be used. An investigation of the whole areas indicates that the most favorable areas for silica rock are in Centre, Blair, Bedford, Huntingdon, Mifflin, and Juniata counties. In Centre County the better areas are in the southwest, in Bedford County in the north, and in Juniata and Mifflin counties in the western and southern parts. Many deposits of usable rock are outside of these areas, but they are not so uniformly good.

Chickies Formation.

The Chickies formation is regarded as of basal Cambrian age. It ranges from a soft, argillaceous, poorly cemented sandstone, through a mica schist to a pure, hard, dense, heavy-bedded quartzite. In places it is a conglomerate. The mica schist phase has been previously discussed in this report under that heading. It represents that part of the formation in which the constituents, other than quartz, have been transformed into muscovite, the colorless mica.

On the whole the Chickies quartzite is harder and a little more difficult to crush than the Tuscarora quartzite. It is also rather more difficult to burn to brick and when first used in brick-making it was deemed necessary to mix some Tuscarora quartzite with it to improve the absorption of water in mixing. This practice was discontinued for a short time, but doing without the Tuscarora rock was not successful, and some of it is now regularly mixed with the Chickies. Some manufacturers claim that a little higher temperature is needed to burn the Chickies quartzite to a good firm brick. If not sufficiently burned these bricks tend to check rather readily.

Distribution. As indicated in figures 2 and 3, outcrops of the Chickies formation are confined to the southeastern part of the State. Exposures are numerous in the area east of Chambersburg and southeast of a line drawn through Chambersburg, Carlisle, Harrisburg and Easton. Exposures are comparatively small and discontinuous. The formation does not make continuous ridges for scores of miles, like the Tuscarora, and it is, therefore, less easy to find the outcrops. On account, however, of the resistant character of the quartzite suitable for brick-making, it forms rather prominent short ridges or knobs and this feature is an important factor in searching for good rock. There are only a few exposures of this rock which can be regarded as of much importance for silica refractories. The remainder of the formation is soft, friable or impure.

There is a large mass on the banks of the Susquehanna at the large bend just above Columbia, another just south of Womelsdorf where the E. J. Lavino Refractories Company has a brick plant, a small knob known as Sugar Head Hill, near Shillington, south of Reading, a large outcrop at Narvon, where the Harbison-Walker Refractories Company has a quarry and one near East Downingtown where the same company carried on rather extensive quarrying operations for several years. An exposure near Reading gives promise of furnishing some good rock, and some of the quartzite around Edge Hill has been used as ganister. Outside of these localities nothing was regarded as of importance.

Physical and chemical properties. The following table indicates the properties of this quartzite as determined by tests of samples from various localities. These tests were made in the same manner as those on the Tuscarora quartzite.

Analyses and tests on samples of Chickies quartzite.

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	Total per-cent	Fusion point degrees C.		Character of deposit	Percent of deposit represented
						Coarser material	Through 150 mesh		
56	97.92	0.80	0.85	0.09	99.66	1,772	1,760	Floe	85
58	97.80	0.92	0.86	0.10	99.68	1,766	1,759	Ledge	70
60	97.51	0.99	1.08	0.11	99.69	1,753	1,737	Ledge	75
63	97.60	0.88	1.13	0.10	99.71	1,787	1,740	Floe	50
64	97.20	1.08	1.35	a	99.63	1,734	1,735	Floe	80

*Not determined.

Number and source of samples.

56. Lebanon County, gap in South Mountain near Newmanstown. From the front ridge, and the percentage refers to it.

58. Lancaster County, Harbison-Walker Refractories Company quarry at Narvon. Dense, hard quartzite with softer band.

60. Lancaster County, on Susquehanna River about 1¼ miles above Columbia. Band about 150 feet thick.

63. Berks County, from Bertolet and Hunter property at Temple, near Reading. Rock is quarried, crushed, and screened for concrete. Mostly friable.

64. Berks County, Sugar Head Hill, ½ mile from Shillington, near Reading. Small hill on which the High Point Stone Quarry is located.

The tests indicate that much of the Chickies quartzite compares very favorably with the Tuscarora in purity and in fusibility. The writer has often been asked whether this quartzite can be regarded as a first-class rock for brick. It is safe to say that it can be, with the qualification that it requires a little more care in selection and

in burning than the Tuscarora quartzite and in some cases where the rock is particularly hard and dense it might be profitable to mix a little Tuscarora or other good grade quartzite with it. This would make the mixture absorb water more readily and permit it to burn at a little lower temperature. This formation is less uniform in quality and it is subject to more rapid changes in character along the strike of the beds than the Tuscarora formation. The hills are not so high and the districts in which the formation outcrops are more thickly settled than those in which the Tuscarora occurs. As a result the land is as a rule more difficult to secure for operations.

PRODUCTION OF RAW MATERIALS.

Cost of lands, and royalties on rock. Most of the rock used for silica brick occurs in hills or mountains on land that is useless for agriculture. Owing to the rapid development of the silica brick industry in Pennsylvania the value of lands containing good quartzite has increased rapidly. A few years ago much land underlain by good rock could be secured at land tax sales and a great deal of such land has been secured by enterprising companies for a few dollars an acre. Most companies are rather reticent about giving out information for publication concerning the cost of property. The figure mentioned in one case as the sale price of the rock rights on land situated near operating quarries was $50 an acre. Some land is held at $100 an acre, and as high as $200 and $250 an acre has been paid for land containing good silica deposits. It is evident that various brick companies have secured the rights to the greater part of the land containing good quartzite situated near the railroad lines. There is much good quartzite, however, in the mountains, in the central part of the State so far from transportation that it is practically valueless at the present time. Most of the land containing good rock and not yet leased or sold for the rock lies in the State Forest Reserves. Two quarries visited are situated on these reserves where land has been leased from the State Department of Forestry. The royalties paid on rock are normally about 4 cents a ton but prices run 2, 3, 4, 5, 7, 8, and 10 cents a ton. During the recent period of inflated war prices for everything some royalties are said to have been higher than 10 cents.

Quarrying.

Two types of quarrying operations are practiced in securing quartzite, (1) quarrying or stripping the loose, broken talus, or "floe rock," which forms great sheets or piles along the mountain flanks, and (2) quarrying the solid or "ledge rock."[4] In stripping the floes,

[4]Bowles, Oliver, Sandstone quarrying in the United States: U. S. Bureau of Mines Bull. 124, Washington, 1917.

which in some cases are a mile or more in length, several hundred feet wide, and from two to thirty-five feet thick the operation is comparatively simple. A plane is constructed, running up the mountain face to the floe and tracks are laid from the plane along the mountain so that the broken rock may be worked in benches (Pl IV). Back switching is used in climbing the steep grades. As rapidly as the rock in one locality is exhausted the tracks are moved to another.

Pl. IV. Stripping operations of E. R. Baldridge Company on floes covering the face of Tussey Mountain along Little Juniata River between Barree and Spruce Creek, Huntingdon County.

The rock is broken with sledges and loaded into the cars by hand. Considerable care must be exercised in removing the loose rock to prevent fragments from rolling down the mountain and injuring the workmen, or to avoid large masses of the talus sliding down over the tracks. In most strippings where grades are very steep masses of talus are left at intervals to serve as anchors or buttresses and thus prevent large slides. In loading, careful sorting is necessary where the floe rock is not of uniform grade. Where one of the adjacent formations lies sufficiently high up on the mountain for its outcrop to supply undesirable material to the talus this material may be discarded.

In stripping the talus practically no blasting but "mud capping" is necessary. This is employed where boulders are too large to be

broken with a sledge. It consists in placing one or two sticks of dynamite on a block which is to be broken, covering these with clay or sand and firing the charge with a fuse. A number of these charges are fired in one firing period so as to interfere as little as possible with the operations in the quarry. Where there are many large and tough blocks, some of these may be drilled by hand or with a jackhammer and the charge is placed in the holes, which are often spoken of as "block holes." A charge of given strength will do more in such a hole than in mud capping but the time spent in drilling is an important consideration.

In quarrying the ledge, or solid rock, an excavation is made either by blasting out the quartzite or prying it out with bars. In some quarries the rock is "tight" and most of it must be blasted; in others much rock may be "seamed" out where the beds are not too thick and there are clay seams and joints along which the blocks separate readily. The drilling in some of the smaller quarries is done by hand but in most quarries the jackhammer drill run by compressed air is used. The tripod drill D24 was also seen in some quarries where it is used to advantage in heavy-bedded rock. Blasting is mostly done in "snake holes" and 40 per cent dynamite is the explosive used.

To save drilling, dynamite may be placed in a hole made with a bar in a clay seam. A small charge is first fired in the hole and this is increased until a large charge of between 100 and 200 pounds of 40 per cent dynamite can be added and a great deal of rock moved.

In some cases the quarries are situated along the crest of a mountain and the overburden of clay and broken rock does not cause much trouble, but in others the debris which is continually working down into the quarry adds much to the expense and danger in quarrying. The debris runs, on the average, about 1 ton in 3 of material removed. It may be considerably more or less than this in various quarries as the relative amount depends much upon the situation of the quarry on the mountain. The ideal location, so far as the overburden is concerned, is in the crest of the mountain. The lower down the mountain side usually the greater danger from rolling boulders or sliding cover and the thicker the overburden, other things being equal. In quarrying, the rocks can be broken more readily working with the dip but the overburden is more troublesome and cannot be so readily controlled as when quarrying in the direction opposite to the dip. Working parallel to the strike is probably most satisfactory where it can be followed. In most places where quarrying is carried on there is, fortunately, very little difficulty in disposing of the waste rock since the majority of the quarries are

situated on mountain faces or hillsides which are uninhabited and unsuitable for agricultural purposes. Most of this debris is moved by hand because the situation of the quarry and the nature of the overburden make it difficult, or impossible, to strip the formation with steam shovels. Scrapers may be used in some places and in one quarry a Thule electric shovel of ¾ yd. capacity was seen in operation for loading dirt or second-grade rock. The drainage problem is of little importance in most of these quarries since they are situated on high lands and natural drainage takes care of the water. Loading is done almost entirely by hand. Automatic loading devices cannot be relied upon for loading high grade rock because they will not sort the material and remove the clay and fragments of inferior quality. The quarry cars used in various quarries hold from 2¼ to 4 tons each. The average man will load 15 to 20 tons of stone a day and where two men work together they will load 25 to 30 tons each in a day. A foreman stated that one man made a record in loading 20 cars in a day, the cars holding about 2¼ tons of stone. The wages paid for loading in different quarries during the summer of 1921 were 17 to 20 cents a ton. In the previous summer they were around 23 cents a ton.

Quarry haulage. Since most of the quartzite quarries are at high levels the rock must be brought down considerable distances to the railroads or brick plants. If the loading station or brick plant is near the foot of the hill on which the quarry is situated the rock is hauled to a tipple at the head of a gravity plane and dumped into cable cars which carry it to the hoppers at the crushing plant or to the bins of the loading plant.

The gravity plane includes a steel cable wound on a drum or around two sheaves, 5 to 6 feet in diameter, in the form of a figure-8. The speed of rotation of the sheaves is controlled by grooved wooden brakes. The rails may be arranged so that there are three, with a switch in the center, or three in the upper part of the plane and two in the lower part with one line of cable below the center and two above. One or more cars may constitute a trip on the plane.

The size and distance of the quarry from the head of the plane determine whether cars shall be hauled by mule or dinky engine or pushed by hand.

The dinky is largely used for hauling floe rock as the distances covered in gathering it are long. It is also employed where the brick plant is more than half a mile from the quarry, as for example, at Mount Union where the Harbison-Walker Company bring their rock across the Juniata from Jacks Mountain, or again at Alex-

andria where the Federal Refractories bring rock from Short Mountain to their plant at Alfarata station.

Some brick companies haul rock a long distance by railroad. The most striking case is the transportation of rock by Harbison-Walker Refractories Company from Water Street, Huntingdon County and from Hannah, Centre County, to their plant at Hays Station, just outside of Pittsburgh. The United States Refractories Corporation bring rock from Three Springs, at the southwest end of Jacks Mountain, to their plant at Mount Union by the narrow gauge East Broad Top Railroad. The General Refractories Company haul their quartzite by the same railroad from their Neelyton quarry, which is on the north side of Tuscarora Mountain about 20 miles from Mount Union.

Relative advantages in quarrying float and ledge rock. Up to the present time by far the greater part of the quartzite used for ganister and silica brick in Pennsylvania has come from the talus floes. As this type of deposit becomes less abundant a much larger proportion of the rock used will be quarried from the ledge or solid formation. Some companies even now have begun to draw their supplies almost entirely from the solid formation. There are certain advantages and disadvantages in quarrying these two types of deposits. The advantages in using the floes lie in the general higher grade of the raw material and the lower cost of quarrying. Quarrying the solid formation permits easier superintendence and easier operation because of restricted area, and in some cases gives greater uniformity in the character of the rock produced.

It is generally admitted that the float rock is of better quality than the solid formation from which it has been broken by weathering processes, because it has been more thoroughly leached of its soluble salts, such as those of calcium, iron, magnesium, and the alkalies. Where the ledge rock is overlain by or is adjacent to calcareous shales or limestones, some of the carbonates of lime and magnesia are likely to be carried in solution into the quartzite. These cause trouble in burning, unless great care is exercised, because the carbon dioxide gas (CO_2) is driven off at a temperature of about 800°C. and it may cause the brick to crumble. The fusibility is also lowered somewhat by the presence of these salts. Owing to the fact that the Tuscarora (Medina) quartzite, so far as it has been quarried in Pennsylvania, usually lies so well up on the mountains above the calcareous rocks it contains very little lime or magnesia. It seems probable, however, that the presence of the carbonates mentioned above may, in some cases, help to explain the failure of brick in the kilns.

A very important factor in the weathering of the floe rock is the removal of the clay which occurs in seams and irregular lumps in the quartzite. This clay is almost entirely removed after the broken rock has been exposed to weathering for a few years. With the removal of the clay, many objectionable impurities, in addition to the clay itself, are lost, since alkalies are absorbed more or less by the clay, and in the cracks where the clay occurs a certain amount of calcium, iron, magnesium and other impurities may be deposited. To dispose of this clay in rock quarried from the solid, some operators have tried exposing the broken rock for several months before crushing it. This helps, but the action is slow, it delays quarrying operations, and, in some cases, necessitates additional handling of rock. Part of the desired results may be obtained by screening and washing the crushed rock.

Another feature about bricks made from ledge rock is a tendency for the bricks to mash or crumble in the kiln unless they are dried longer than those made from floe rock. This difficulty appears to be due to a larger amount of "quarry water" in the solid stone since it has not been exposed on the surface as long as the broken rock. On account of this, it is probable that there is more colloidal matter in the solid than in the broken rock. Thorough drying would dispose of the moisture and the effects of the colloidal matter and thus prevent the brick in the bottom of the kiln from crumbling under the load.

The relative cost of quarrying floe rock and the solid formation, according to figures given by men experienced in quarrying both types, varies from fifteen to fifty per cent, depending upon quarry conditions. The fact that floe rock can be quarried from fifteen to fifty per cent cheaper than the solid rock is due to almost negligible expense for blasting and removal of dirt. Such an operation requires more track but the track is not broken so frequently and it has longer life. In quarrying the solid formation the haulage distance is much less, superintendence is easier, and in inclement weather there is some advantage in working in a restricted and more sheltered area.

DESCRIPTION OF PROPERTIES AND PLANTS.

It is impracticable to describe every locality in the State where Tuscarora or Chickies quartzite may be found but a brief description of the silica brick and ganister plants and some of the quarries is given below. We were not able in all districts to learn the name of the owner of tracts of land which have been taken up for silica.

Harbison-Walker Refractories Company.

The Harbison-Walker Refractories Company, with head offices in Pittsburgh, is the largest operator in the State and controls very large reserves of quartzite in many places besides those where active operations are now in progress. This corporation originated as the Harbison and Walker Company, and in 1887 made their first silica brick at their Star plant. In 1902 the Harbison-Walker Refractories Company was organized from the one previously existing. This company manufactures practically all sizes and shapes of silica brick as well as fire clay, chrome and magnesia brick. Its silica brick plants in Pennsylvania are at Hays Station, close to Pittsburgh, at Mount Union and at East Downingtown. The Hays plant depends for its quartzite on the talus floes on Tussey Mountain, near Water Street, Huntingdon County and on Bald Eagle Ridge near Hannah, Centre County. The rock is shipped in steel cars and crushed at the plant. The stripping, or quarrying operations near Water Street are extensive. A plane running down the mountain side from an elevation of 430 feet above the Juniata River brings the rock down to the Pennsylvania Railroad close to Goodman Station. From this plane, tracks have been run along the mountain face for thousands of feet. Another plane a short distance down stream was formerly used in stripping a large area of talus. The talus in this area is from 1 to 13 feet thick. A very large floe in the gap just below the operations mentioned, has not been worked because it seems to have in it too many red and soft fragments from the Juniata formation, or the more impure parts of the Tuscarora.

Near Hannah Station on the Pennsylvania Railroad a plane runs up to the workings near the top of Bald Eagle Ridge where the talus has been stripped off for about three-quarters of a mile along the mountain face, over a width of about 250 yards. The depth of the talus is estimated at 3 to 7 feet with an average of 4 feet. There are many large "sandy" boulders in it and a good many fragments, high in iron, which have been discarded. A new plane is to be operated about one-half mile up the railroad track.

Hays. The plant at Hays contains 58 kilns in four sections. 26 kilns are used for silica brick and the others for other refractories. They are of the 36 and 40-foot type, holding 172,000 to 175,000 brick each. The capacity of the plant is said to be about 235,000 9-inch equivalent brick per day. Waste heat from kilns, waste steam and live steam are used for drying, under various conditions. All regular brick are made by the slop-mud process and all shapes are mauled. The same lime content is used for ordinary brick and shapes and

the better molding conditions for shapes are secured by finer grinding of the mud, the time of grinding being increased about one-half.

Mount Union. The plant at Mount Union is very large and is situated close to one of the best sources of quartzite in the State. The plant was opened in 1902 as the Mount Union Silica Brick Company's plant but was shortly afterwards taken over by the present owner. It contains 34 kilns, twenty-seven 40-foot and seven 32-foot. The normal daily output is about 240,000 9-inch equivalent brick. Silica cement is made at this plant and practically all varieties of shapes. The plant is operated by purchased electric power (Pl. VI).

The rock used at this plant is from the floe on Jacks Mountain. Some of the finest floes in the State occur along the sides of the gap where the Juniata River cuts through the mountains above Mount Union (Fig. 4 and Pl. V).

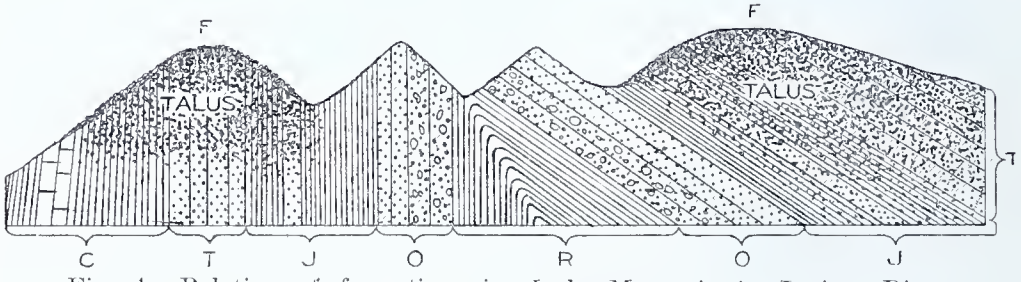
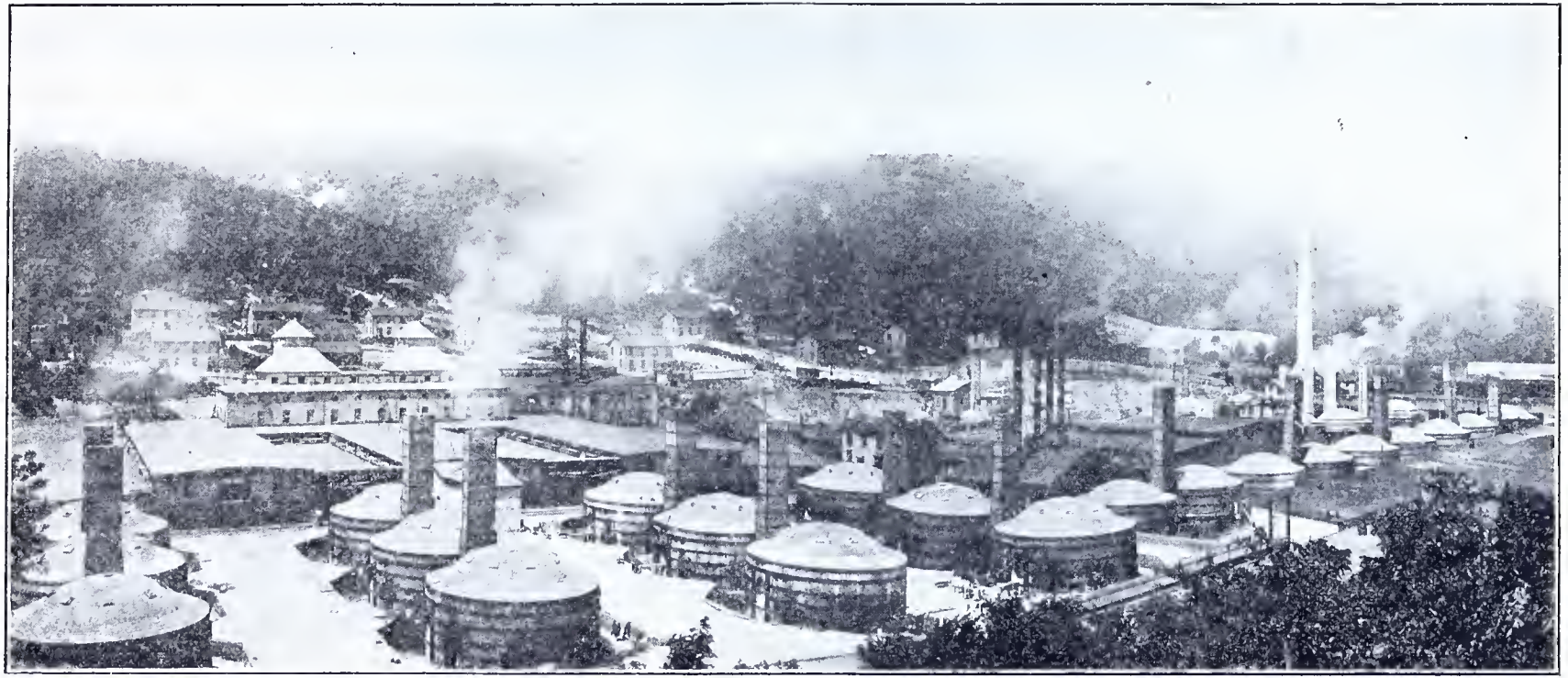


Fig. 4. Relation of formations in Jacks Mountain in Juniata River gap at Mount Union Talus is indicated as working down the slopes over different formations.

C—Clinton formation; T—Tuscarora quartzite; J—Juniata formation; O—Oswego sandstone and conglomerate; R—Reedville shale; F—Floes.

Pl. V. Floe on Jacks Mountain, along the Juniata River at the operations of the Harbison-Walker Refractories Company, Mount Union, Huntingdon County.



Pl. VI. Harbison-Walker Refractories Company plant at Mount Union, Huntingdon County.

The loaded cars are collected by cable and hauled by dinky engines across the Juniata to the brick plant. Most of the talus has been stripped from the south side of the gap but tremendous quantities still exist on the north side. One of the most prominent floes is in Jacks Spring Hollow. It is about one-quarter mile wide by 600 feet up the mountain face and about 5 to 15 feet deep with an average of 8 feet. The blocks are comparatively large (Pl. VII).

Pl. VII. Floe of Tuscarora quartzite, Jacks Spring Hollow, Harbison-Walker Refractories Company quarry, near Mount Union, Huntingdon County.

Another large floe occurs within the gap farther up the river, near Mapleton. It has not been worked yet. The most southeastern portion of the floe which has been worked is comparatively high in iron and rather "sandy." Part of it has been rejected in the quarrying operations.

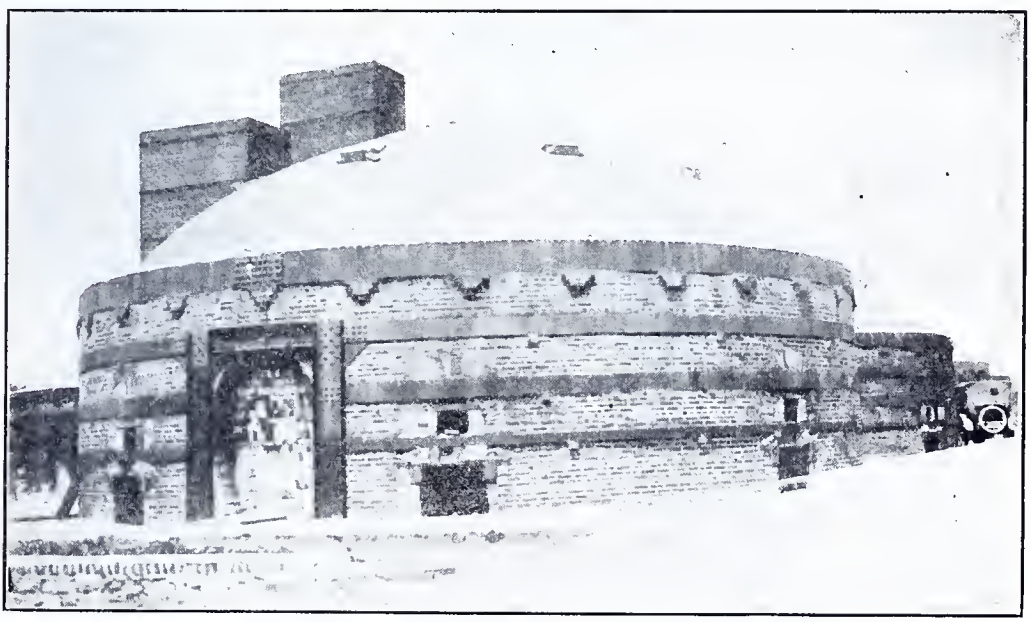
Downingtown. The Downingtown plant of this company is operated on Chickies quartzite. When first opened, some Tuscarora quartzite was mixed with the Chickies to improve the mixture. Later this practice was temporarily discontinued, but the company soon returned to the use of some Tuscarora rock.

The brick plant and the quarry adjacent to it were opened in 1917 and the new quarry at Narvon was opened in the winter of 1921. There are six 40-foot kilns with a capacity of about 175,000 brick each. Coke oven brick and silica cement are not made at this plant. A new drier was recently installed which is expected to dry brick in from 12 to 16 hours. The quarry in the hillside just east

of the brick plant is connected by tramroad and the rock is hauled by dinky engines. In this quarry heavy-bedded, massive, hard quartzite dips 55° S 20° E. Pure quartzite 25 feet thick is exposed for about 500 feet along the strike. Beneath this band the rock is much softer and less pure. It contains narrow schistose bands. This quarry was practically abandoned at the time of our visit and the rock was to come from the Narvon quarry in future. In this quarry, the exposure at the time of Mr. Taylor's visit was about 30 feet long and 20 feet high. The rock is a very dense, bluish quartzite. Streaks of soft and badly colored rock are discarded in quarrying.

Superior Silica Brick Company.

The plant of the Superior Silica Brick Company is near Port Matilda, Centre County, on the Pennsylvania Railroad in Bald Eagle Valley (Pl. VIII). It began operations in the autumn of 1918. There are eight 38-foot kilns each with a capacity of 140,000 brick. The daily capacity is about 50,000 brick. The plant machinery consists of one Champion 5X crusher and three 8-foot wet pans.



Pl. VIII. Typical circular, down draft silica brick kiln showing the iron bands, fire boxes, port holes, and door bricked up after the kiln has been charged. Superior Brick Company plant, Port Matilda, Centre County.

The rock comes from large strippings about one-half mile long, on a floe from 1 to 20 feet thick with an average of 5 feet, and also from a quarry in the ledge rock. This quarry is about 300 yards long and the band of quartzite exposed is 90 feet thick. It may be inferred that the whole workable formation here is 250 to 300 feet thick. The beds stand vertical and some are as much as 3 feet thick,

In some places clay partings separate the massive beds. Some pebbles of bluish to greenish clay occur in the quartzite. The company's property is said to extend $3\frac{1}{8}$ miles along the Bald Eagle Ridge. Rock is hauled to the plant by dinky engines. Drilling is done by hand.

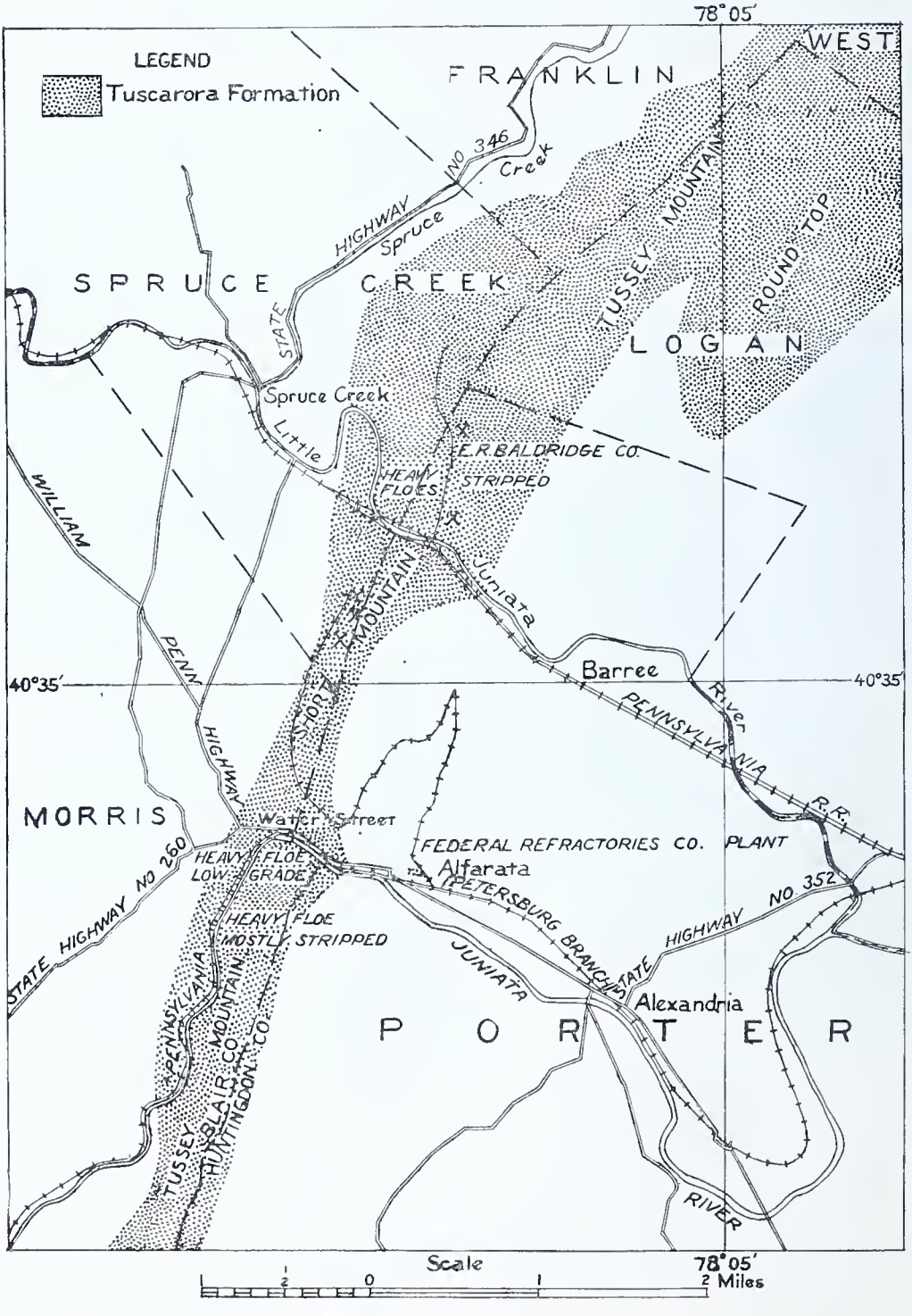


Fig. 5. Map of Alexandria-Barree district.

Federal Refractories Company.

The Federal Refractories, a subsidiary of the Stowe-Fuller Company, with head offices in Cleveland, Ohio, operate a silica brick plant at Alfarata Station, near Alexandria, Pa. (Fig. 5). The post office address of the company is Alexandria.

The daily capacity of this plant in silica brick is about 40,000 9-inch equivalent brick with the addition of 25,000 chrome and magnesia brick per month. There are 14 silica brick kilns each 36 feet in diameter and capable of holding 80,000 brick. The rock is crushed in a Farrel jaw crusher, model B, and ground in four wet pans 8 feet in diameter.

The rock is quarried on the north face of Short Mountain on land leased from the State Department of Forestry. Short Mountain is just south of the village of Spruce Creek, between two branches of Juniata River. The quarry was opened in 1904. It is about 450 feet long with a working face from 10 to 90 feet high. Drilling is done with two compressed air drills and blasting by mud capping and snake holing. The rock consists of reddish to pure white sandstone and quartzite with thin seams of clay and shale distributed through it. At the base of the quarry there is a deep red shale indicating that the rock is grading into the red Juniata below (Fig 6).

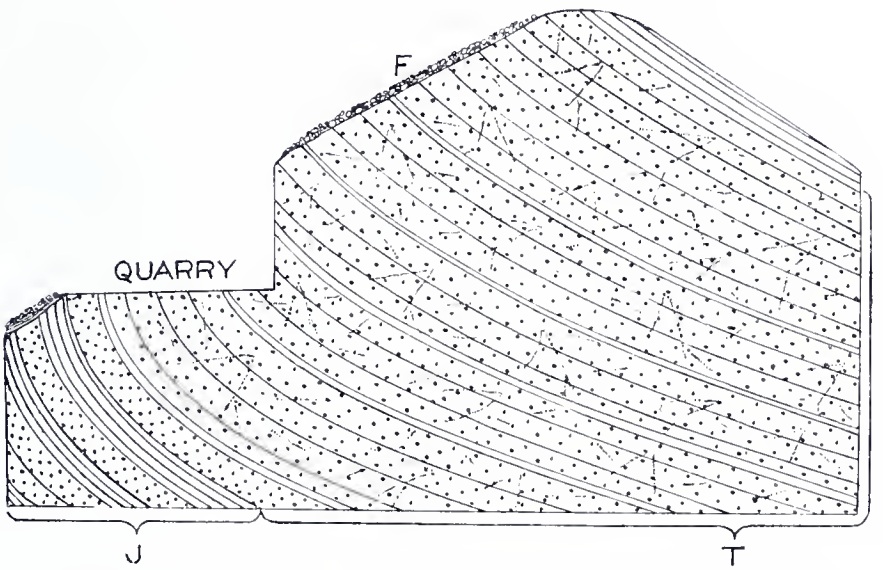


Fig. 6. Structure section at quarry of Federal Refractories Company on Short Mountain, near Water Street, Huntingdon County. Shows one way in which red rock from Juniata formation may contaminate floe rock from the Tuscarora quartzite in lower portion of floe.

J—Juniata formation; T—Tuscarora quartzite; F—Talus floe.

Above this there are several seams of bluish shale varying in thickness from 2 inches to 2 feet. The overburden in this quarry is not

more than 2 to 3 feet thick, in addition to the floe rock. The shaly material readily separates from the quartzite in quarrying, but it is necessary to discard about one-third of the rock handled. The mountain rises over 200 feet above the base of the quarry.

Another quarry was formerly operated 1180 feet farther east and around the end of the mountain in the gap. It is 445 feet long and exposes from 1 to 50 feet of strata in the face. The strike is N. 30° E and the dip 10-15° S 60° E. The rock varies from a heavy-bedded, gray to white quartzite, to a reddish sandstone and there are three seams of shale from 6 inches to 2 feet thick about equally distributed throughout the face. The northern 30 feet of this quarry is in the red Juniata shale and sandstone which underlies the Tuscarora formation. As shown by the accompanying diagram (Fig. 6) the beds at the outer border of the quarry are rather sharply turned upward. This seems to be at least partly due to the drag of the beds in the large fault which runs along the foot of Tussey Mountain in this region and cuts out the front ridge of Oswego formation. There is considerable talus on the property and much of it has been stripped off. It is from 2 to 12 feet thick and averages around 3 feet. In the lower portions of the floes there is much ferruginous rock due to the mixing of fragments of the red Juniata with the Tuscarora. Higher on the mountain the talus is purer and whiter and is of good quality. The rock is carried to the brick plant by rail around the southwest end of Short Mountain.

General Refractories Company.

The General Refractories Company, of which Ex-Governor William Sproul is president, has ten plants manufacturing refractories in various parts of the country. The head office is in Philadelphia and plants are located at Mount Union, Sproul, Sandy Ridge, Karthaus, West Decatur and Mill Hall, Pa., at Joliet, Ill., Ableman, Wis., and Hutchins and Olive Hill, Ky. The Mount Union, Sproul and Ableman plants manufacture silica brick only. The plant at Sproul, opened in 1911, uses rock from the quarries of the J. D. Hartman Company on Dunning Mountain. There are 22 kilns 32 feet in diameter. The two crushers are of the Champion Good Roads Machinery type. There are 5 wet pans and 1 dry pan, the latter for grinding silica cement. The daily capacity is about 90,000 9-inch brick. At this plant an elaborate silica brick machine, mentioned on page 83, has been constructed and tested under the supervision of the superintendent, Mr. McCarty.

The Mount Union plant (Pl. IX) has 23 kilns, each 32 feet in diameter and capable of holding about 85,000 brick. The capacity of this plant is about the same as that at Sproul. There are two

crushers, one a Farrel 24 x 36, Style B, and the other a Champion 5X type. Grinding is done in six 8-foot wet pans of Clearfield type, motor driven. The plant is fully electrified; power is obtained from the Raystown Power Company.

Pl. IX. General Refractories Company plant at Mount Union, Huntingdon County.

The quartzite for this plant, prior to 1918, was taken from a quarry near Mapleton, on the mountainside. It is now brought from the company's quarry at Neelytown, on the northwest side of Tuscarora Mountain, which was opened in 1918. It is shipped over the East Broad Top narrow gauge railway. At Neelytown most of the rock comes from the floe which averages 8 to 10 feet in thickness and forms a band some 400 feet wide along the face of the mountain. The company is said to have leased about 5 miles of the mountain face and nearly 2000 feet has been stripped. A quarry has been opened on the ledge for 100 feet giving a 30-foot quarry face with a dip of 80° N 60° W. There are a few shale seams in the formation and some beds are comparatively coarse grained, but free from impurity. The ledge and floe rock are mixed together and carried from the quarry to the tipple at the railroad on a gravity plane 2900 feet in length.

United States Refractories Corporation*

This company operates a silica brick plant at Mount Union, using rock shipped over the East Broad Top narrow gauge railway, from a quarry on Jacks Mountain, near Three Springs (Fig. 7). The plant is equipped with one large Kennedy No. 7½ gyratory crusher

*Formerly Mount Union Refractories Company.

for breaking the larger rocks and with three Champion 5X jaw crushers. There are 29 kilns of 21, 32, 36 and 40 foot sizes and the daily capacity of the plant is about 150,000 brick. Coke oven, retort and metallurgical furnace brick are manufactured. A silica cement is made by mixing brick bats with the nearly white clay obtained from the Rockhill pits near Shirleyburg.

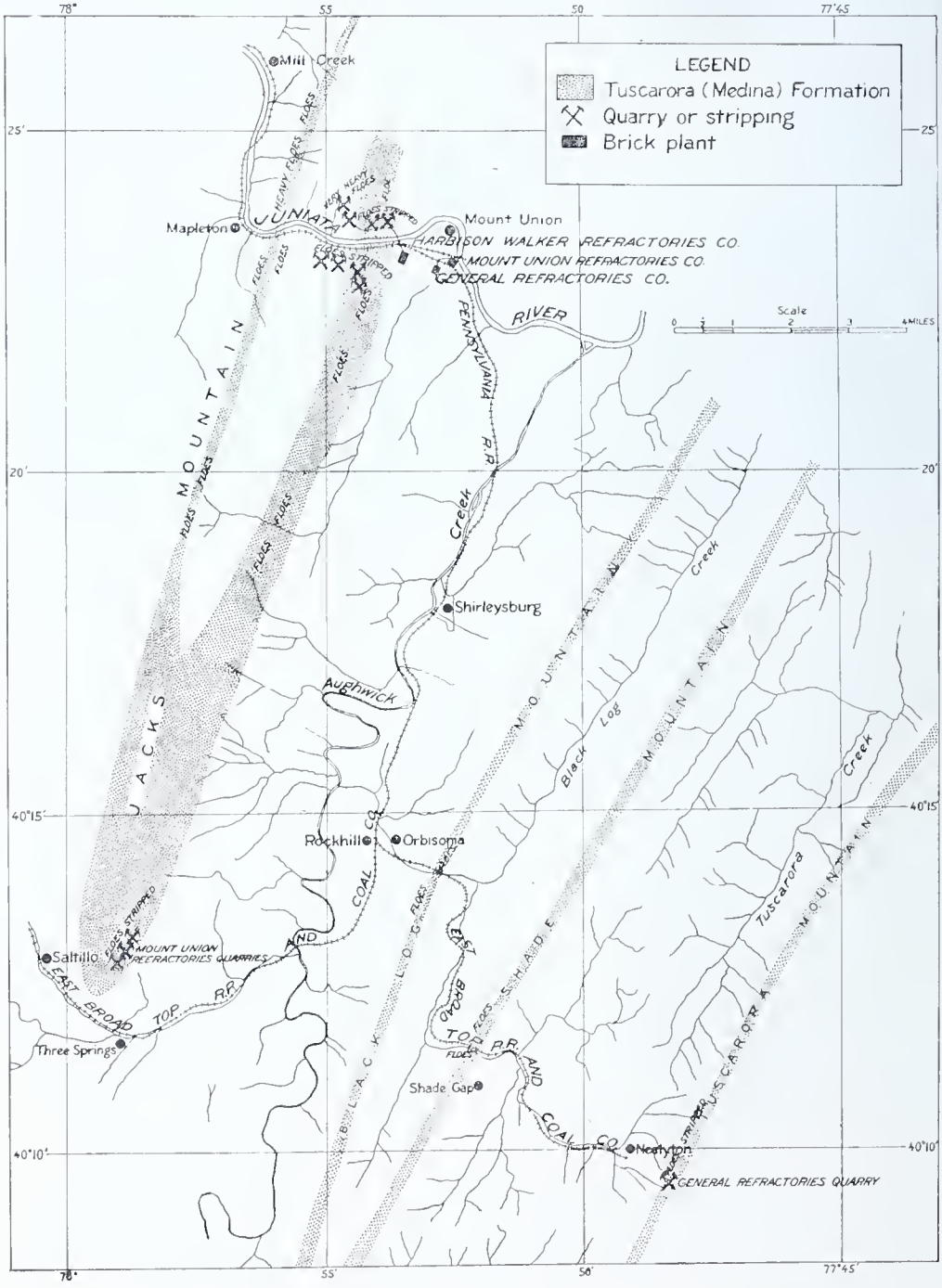


Fig. 7. Map of Mount Union-Three Springs district, Huntingdon County. Plant and quarries of Mount Union Refractories Company are now owned by United States Refractories Corporation.

The quarry is about 400 feet above the railroad and the rock is brought down to the tracks at a point about ⅛ mile from Three Springs Station, by a gravity plane 2300 feet long. Horses are used for collecting and a dinky engine for hauling the cars to the head of the plane. Both float and ledge rock have been worked. The talus has been stripped off for about one mile along the side of the mountain. The solid formation lies nearly flat, the dip being only about 8°, and it varies in character from heavy-bedded, highly pure, hard quartzite to thin shale beds. In one quarry face about 100 feet high and 100 feet long the beds are rather thin and shaly near the top but heavy-bedded and much purer near the base. There is one 25-foot band of excellent rock. The shale seams run up to 3 and 4 feet in thickness. The quartzite is very hard to drill and for that reason little drilling is done. Hand drills are employed where holes are necessary. Most of the rock is pried loose with bars. Much mud capping is done and it is said that sometimes a box of dynamite has been used on one large block. This is expensive for explosives but it saves drilling. The peculiar fossil, *Arthrophycus alleghenensis,* occurs abundantly in this quarry.

Standard Refractories Company.*

The Standard Refractories Company's operations are at Claysburg. The company controls a number of areas of Tuscarora quartzite along Dunning Mountain, as well as a large mass of Chickies quartzite on Susquehanna River near Columbia, Pa. One property includes 3 miles on Dunning Mountain, extending northward from Osterberg and another is situated in Dutch Corners. The quarry at Claysburg was opened in 1913 and the following year silica brick were made at the plant. The plant has 20 kilns each 38 feet in diameter and the daily maximum capacity of the plant is about 140,000 brick. Retort, glass tank, and metallurgical furnace brick are all made here, but no coke oven brck or silica cement. The crushing equipment consists of 2 Champion 5x crushers. There are six 8-foot pans with individual 60 h. p. motor drive. The kilns are connected with 4 boiler stacks each 176 feet high, which can be used for increasing the draft in the kilns if necessary. These stacks are equipped with auxiliary fire boxes. Waste heat from the kilns is used to operate a steam plant which generates electricity for use in the town of Claysburg as well as around the plant. This is a very commendable form of conservation.

One of the silica brick machines described, on a later page has been experimented on in this plant.

The rock for the plant is brought down from Dunning Mountain by a gravity plane 2800 feet long and with a grade of 30°. The

*Sold August 8, 1923 to the General Refractories Company.

quarry is 1650 feet long and exposes rock 90 feet thick. It is evident that the available thickness of rock here should be about 250 feet. The talus is stripped for 2500 feet and the length of the property is 6000 feet. Drilling is done by Ingersoll Rand jackhammer and D 24 tripod drills. The quarry cars holding 4 tons each are handled by a Jeffrey storage battery motor. In this quarry a ¾-yard Thule electric shovel has been used in loading second grade rock and dirt. On account of the clay seams in the formation about one-third of the material handled must be discarded. One of these seams near the base is 4 feet thick and a few feet above it there is a bed of coarse, sandy rock also about 4 feet thick. Several impure seams occur above these but they are comparatively thin. Some of these are bluish plastic clay. The beds dip 45° S 60° E and the quarry advances in the direction of dip. *Arthrophycus alleghenicnsis* is common in this quarry.

This company is said to control the rights on the ridge of Chickies quartzite at the large bend in Susquehanna River just above Columbia. At this point a band of good quartzite about 150 feet thick, outcrops. The high grade rock gradually passes east and west into a soft, friable sandstone and impure quartzite of no use for ganister.

Pl. X. Haws Refractories Company plant in Lewistown Narrows, at Hawstone, Mifflin County.

Haws Refractories Company.

The main office of the Haws Refractories Company is at Johnstown. The silica brick plant and shipping station is Hawstone 4.8 miles east of Lewistown on the main line of the Pennsylvania Rail-

road. The local post-office is Ilaws. Operations were started there in 1917 (Pl. X). At the time of our visit, there were 11 kilns and a foundation for the twelfth. Each kiln holds about 125,000 brick and the daily capacity of the plant is 55,000 brick. Two crushers of the Champion 5x type are used. Rock is obtained from the large floes on the mountain directly above the plant. It is brought down through a vertical distance of about 360 feet by a gravity plane approximately 2000 feet long. The area stripped runs about 1000 feet along the mountain and about 300 feet up its face. The talus is very thick in these floes, in some places reaching 25 and 30 feet. The larger blocks, which are 1½ to 4 feet in diameter, slide down over a layer of smaller fragments 2 to 3 inches in diameter.

Talus on ridges to the south is mixed with the Juniata red rocks and is not suitable for making silica brick.

This company is said to own the land along this mountain from Shawnee nearly to Denholm and also the land covered with floes on the north side of the river.

Van Dyke Silica Brick Company.

The main office of the Van Dyke Silica Brick Company is at Johnstown, Pa. and the local office at Mifflin. The silica brick plant is at Van Dyke 8 miles east of Mifflin on the main line of the Pennsylvania Railroad. At the time of the writer's visit this plant was under construction. The equipment specifications called for two Champion No. 6 crushers, a drier heated by both waste heat and live steam, and a unit of 12 kilns, each 32 feet in diameter. A new departure in the construction of these kilns is an additional flue. This flue, 18 inches in diameter, is in a small stack built on the opposite side of the kiln from the main stack which contains two flues and which is connected to two kilns in the usual way. The object of adding this extra flue was to equalize the distribution of the heat in the kiln. After the fires are burning well the draft in the large flue is dampened a little and the small flue is opened, thus drawing a proper proportion of the heat toward that side of the kiln. It is expected that a kiln will be burned in 5½ days and there will be no soft brick in that part of the kiln most distant from the main flue. These kilns have eight fire boxes, each 5 feet 9 inches deep by 4 feet wide.

Quartzite is to be taken from Tuscarora Mountain immediately behind the plant. It will be brought down by a gravity plane about 3000 feet long, which was formerly in operation when rock was shipped from this property to the Harbison-Walker plant. It is

said that the company controls 5700 acres in Juniata and Perry counties. Only talus has so far been utilized but the solid formation which underlies it must be about 400 feet thick. The floes are not heavy here and they lack uniformity in depth. In places they are 10 to 15 feet thick with an average of 5 feet over a considerable area. There is much small timber on their surface. The rock varies from dense, white quartzite through reddish and brownish friable sandstone to a small-pebble conglomerate. To outward appearances it does not appear attractive for brick-making but it is claimed that it has been thoroughly tested and found to be quite satisfactory.

E. J. Lavino Refractories Company

This company's plant is between Womelsdorf and Sheridan on the Philadelphia and Reading Railroad. The local office is Womelsdorf and the head office is in Philadelphia. The plant contains eight 38-foot kilns with a capacity of 140,000 brick each. The daily capacity of the plant is reckoned at 30,000 9-inch brick and it is intended to increase this to 60,000. All molding is done by the semi-dry process. There are three 8-foot underdriven wet pans of Clearfield type and 12 lime mixers. The brick are burned a little longer than those made from the Tuscarora quartzite. All crushing for this plant is done at the quarry by a 5x Champion jaw crusher, and the crushed rock is carried to the plant by an aerial tram 1 mile long. The buckets carry 500 pounds each and the operation of loading and unloading is automatic.

Two Ingersoll-Rand air drills operated by a compressor of the same make, are used in quarrying. Blasts are fired by electric detonators. Blocks are broken by the mud capping method.

The quarry in the Chickies quartzite was opened in 1919. It is 430 feet long with an exposed face of 30 feet. The rock is hard and heavy-bedded (Pl. XI). The quarry is in the face of the front ridge of South Mountain near the Berks-Lebanon county line. This company owns the land for about 300 yards east of the quarry and westward a little beyond the road in Newmantown Gap. From an examination of the quartzite in various directions from this quarry it is evident that there is no considerable quantity suitable for brick-making south of a line which may be drawn roughly parallel to the face of the mountain. This line runs along a hollow between the first and second ridges and crosses the road through the Newmantown Gap immediately above the point where the creek crosses the road in this gap. To the northeast the limits of the good rock can be placed at a point directly south of Ryeland. To the southwest the front ridge is promising to a point directly east of Kleinfeltersville. Elsewhere the formation is coarse, soft or impure.

Pl. XI. E. J. Lavino Refractories Company quarry in Chickies quartzite, on South Mountain, near Newmantown, Lebanon County.

E. R. Baldridge Company.

The Baldridge Company, with head office in Hollidaysburg, holds 500 acres near Barree, 25 acres at Wolfsburg, Bedford County, 25 acres at Flowing Springs and a little near Reservoir, not far from Hollidaysburg. The rock is shipped for ganister, ferro-silicon and highway material, and is being tested to determine its qualifications for railroad ballast. It would seem that the harder, tougher rock which will not crumble should be quite suitable for ballast.

The operations of this company at Barree, on the Little Juniata, are quite extensive. Plate IV shows the stripped floes on Tussey Mountain above Barree. These floes are very thick near the foot of the mountain, one of them being nearly 35 feet. They have been stripped from top to bottom of the mountain for about 1/3 mile in length and probably averaged 5 feet. The Juniata formation, which outcrops well up near the top of Tussey Mountain contaminates the talus on the northwest side with red rock. Besides using the floes two quarries have been worked along the strike of the beds. One is high up on, and the other near the foot of the mountain. The dip is about 30°. The Tuscarora formation is estimated at 300 feet thick and is made up of hard, white quartzite and sandstone with shale seams from 3 to 6 inches thick. The shaly layers carry remarkable examples of the fossil, *Arthrophycus alleghenicnsis*. Joint-

ing is well developed in the quarries and much of the rock can be loosened with bars. Drilling is done with steam and hand drills and mud capping is employed a great deal in breaking blocks.

The rock is crushed in a 5x Champion jaw crusher and screened in trommels of 4 sizes: (1) fines, like sand, (2) chips up to 5/8 inch, (3) ¾ inch, and (4) ballast, about egg size, or ¾ to 2½ inches.

At Wolfsburg a quarry has been opened on the nose of Wills Mountain about ¾ of a mile from the station. It is 1150 feet from the railroad, on a spur track. There are two openings 380 feet apart. The first is 830 feet long and the second 430 feet. The cuts follow the strike and expose a face about 75 feet high. The rock is coarse grained and ranges from well cemented, hard quartzite to soft, coarse sandstone. In the second quarry a great deal of dirt has been encountered.

Very little quarrying has been done on the other properties of this company.

J. L. Hartman Company.

The Hartman Company of Hollidaysburg, controls a large acreage on the mountains in that part of the State. According to J. D. Hartman, manager of the company, the properties consist of the following areas: The land along the face of Lock Mountain, extending from a point one mile northeast of Flowing Spring for 8.2 miles southwest to the loop; at Point View 6/10 miles on the right hand side of the river and 4 miles along Canoe Mountain to the northeast; on Dunning Mountain from Reservoir for 2 miles to the Kier Fire Brick Company's property near the gap above Kladder; 3/10 miles on the north side of McKee Gap (1½ miles south of McKee Gap is owned by Peter S. Duncan, Hollidaysburg); 1 mile between Duncan's property and the Standard Refractories property; from the Standard Refractories property for 3 miles southward along Dunning Mountain; and 4/10 miles on the south side of the gap at Loysburg. Large talus floes in the vicinity of the gap above Kladder are 3 to 10 feet thick and of good quality. The surface rock has not been stripped here. Near McKee Gap the floes have been stripped. A large quarry was opened on the northeast side of this gap, but has been abandoned because of tight rock and overburden. An excellent section of the Tuscarora formation with the beds standing vertical may be seen in this excavation. Measuring from the top of the formation, that is, from the northwest side, there is 200 feet of practically clean quartzite and sandstone, followed by 50 feet of interbedded deep red shale with bands of bluish and greenish talcose and serpentinous shale and quartzite. About three-fourths of this 50 foot section is good quartzite. This band is

followed by 95 feet of reddish, hard sandstone, most of which is not of ganister quality. Beyond this band is low ground underlain by the Juniata formation. The Tuscarora formation contains a little iron pyrite, especially in the impure beds. The formation is 345 feet thick and the quarry face is 250 feet wide, and 175 to 200 feet high.

The talus on the properties between McKee Gap and the Standard Refractories property at Claysburg has not been stripped.

On the property south of the Standard Refractories' the talus has largely been removed. The floes were large and averaged 3 to 4 feet thick, in bands 250 to 300 feet wide. A quarry operated on this property for some time, along the summit of the ridge is 740 feet long with an exposed face of 50 feet in maximum height. The strike of the strata is N 40° W and dip 50° N 50° E. The eastern edge of the quarry is close to the contact between the Tuscarora and Juniata formations. The beds are bent and broken. Near the middle of the 50 feet of rock exposed there is an 11-foot band of very massive quartzite of good quality and lying directly above it is a 4-foot band of coarse sandy rock, the relations being similar to those in the quarry of the Standard Refractories Company to the north of this one. Arthophycus and ripple marks are characteristic of the shale beds in this quarry. There are a number of buildings, including a stone boiler house and blacksmith shop. A tram leads from the workings down to Sproul and the rock for the General Refractories plant at Sproul comes from these operations of the J. D. Hartman Company. The talus has been worked along the mountain face for about 1¼ miles to the south of the quarry. The rock carries a little pyrite and the lower portions of the floes contain considerable thin-bedded impure rock.

Very extensive stripping operations have been carried on along the northwestern face of Lock Mountain which was formerly covered with floes, and much rock has also been removed from the mountain at Point View.

On top of Canoe Mountain close to the southwest end a quarry has been opened known as Canoe Mountain quarry (Pl. XII). The working face in this quarry is about 75 feet high and exposes altogether 175 feet of the Tuscarora formation. The lower 25 feet contains some thin seams of red shale and many red and green shale beds are crowded with *Arthophycus alleghenicnsis* (Pl. XIII). This fossil is much less abundant in the upper than in the lower beds of the formation but specimens occur throughout. There is much dirt to handle in this quarry as the overburden runs from 3 to 10 feet and the formation contains a number of clay seams. The

quartzite is, however, of high purity. The dip of the beds is 40 to 45° E. and the operations are carried on opposite to the direction of dip.

Pl. XII. Canoe Mountain quarry of J. L. Hartman Company, Point View, Blair County

Pl. XIII. Fossils (Arthrophycus allegheniensis) on Tuscarora sandstone in Canoe Mountain quarry of the J. L. Hartman Company, Point View, Blair County.

A gravity plane has been used to bring the rock down to Moore's Mills in the valley. Considerable stripping has also been done along the northwest face of Canoe Mountain for ⅓ mile above Moore's Mills.

Other companies producing ganister.

The Kier Fire Brick Company, with head office in Pittsburgh, controls a stretch of quartzite about 1 mile long on Short Mountain, the continuation of Dunning Mountain between Dry Gap, above Kladder, and McKee Gap, Blair County.

A siding about ⅓ mile northeast of Brookes Mills runs back to a plane leading to the workings of this company. This plane is 4700 feet long and rises 750 feet to the quarries on the mountain. The two quarries have working faces of about 100 feet each. One quarry is 275 feet long and the other 245 feet. The overburden is heavy (10 to 15 feet), and a plane about 75 feet long has been run up to the top of the quarry so that the overburden as stripped may be carried directly to the dump and kept out of the quarry. The beds, of which about 60 feet are exposed, are greatly disturbed. The rock is hard, dense quartzite with a few bands of clay interspersed through it. No crushing is done here and the rock is shipped as it comes from the quarry.

A number of comparatively small operations have been carried on at the following points by different concerns: In Paddy Mountain by the Bessemer Loam and Sand Company; on Bald Eagle Ridge in the Milesburg Gap, by Mr. Shad; in the gap at Buffalo Mills by M. V. Brant; at Madly by the Leap Ganister Company; several small quarries along Wills Mountain; at Cliff, Evitts Mountain by Mr. Tate; at Mount Dallas where considerable stripping and quarrying has been done by W. & J. Barclay; in the Lehigh Gap, Blue Mountain, by W. H. Hailer; and in Edge Hill by Kenyon Brothers. Nearly all of these operations were begun during the war and all had closed during the depression which followed it. In some cases the rock quarried was of inferior quality, or it was quarried under difficult conditions and at a cost prohibitive in normal times so some of the workings will not be reopened. Others will again operate under favorable conditions. There is so much high grade quartzite in Pennsylvania that many properties which contain good rock may not find a satisfactory market for some years.

A number of companies have shipped a considerable quantity of quartzite for ferro-silicon. Much of the rock shipped is too high in iron to make silica brick or ganister but it is otherwise of good quality. There seems to be no definite specifications for the per-

centage of silica or iron required in rock for ferro-silicon, since the proportions of silicon and iron in the manufactured product vary considerably. The main manufacturing center for this product seems to be Niagara Falls, N. Y.

CHEMICAL PROPERTIES OF SILICA BRICK.

The average first grade silica brick contains about 95 per cent silica; 0.75 to 1.75 per cent alumina; 0.50 to 1.60 per cent iron oxide; 1.80 to 2.00 per cent lime; and less than 0.50 per cent each of magnesia and alkalies. The following are analyses of first grade silica brick manufactured from the Tuscarora (Medina) quartzite in Pennsylvania. These analyses have been furnished by the kindness of two of the companies manufacturing these brick.

Analyses of first grade silica brick

SiO_2	95.22a	95.26	95.60	95.42	95.10	95.55	95.16	95.21	95.38
Al_2O_3	1.91	1.02	1.32	1.40	1.42	2.00	0.68	0.27	1.25
Fe_2O_3	0.42	1.21	0.85	1.02	0.96		0.62	2.15	0.45
CaO	1.70	1.94	1.85	1.94	2.08	1.50	1.96	1.93	1.99
MgO	0.01	0.14	0.15	0.16	0.21	0.30	0.46	0.09	0.20
Alkalies		0.39	0.38	0.29	0.18	0.40	0.54	0.39	0.55
Loss on ignition	0.74					0.10	0.36		
Total percent	100.00	99.96	100.10	100.23	99.95	99.85	99.78	99.94	99.82

a From Baraboo quartzite.

An analysis of a lime bonded second grade brick made from the Homewood sandstone shows the following composition: SiO_2, 91.48; Al_2O_3, 4.40; Fe_2O_3, 0.98; CaO, 2.47; and MgO, 0.14 per cent.

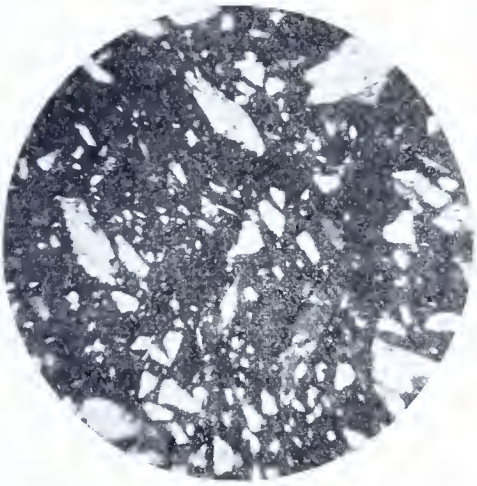
The following analyses indicate the chemical differences between a high grade well-bonded brick and a weak discolored brick. The latter is a reddish-brown brick which breaks with but a slight blow and the photomicrographs (Pl. XIV, A and B) show that the bond contains a large amount of iron oxide which apparently has not properly combined with the silica and lime. The weakness apparently is due in part to insufficient burning.

Analyses of silica brick.

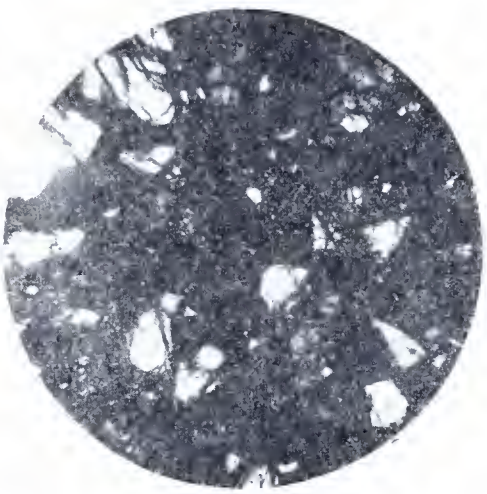
	Well-bonded	Weak
SiO_2	95.60	95.08
Al_2O_3	0.92	1.06
Fe_2O_3	0.96	1.44
CaO	2.08	2.10

Effect of lime. The lime content of ordinary silica brick and of special shapes varies considerably. It may be increased to about 3 per cent by weight for special shapes as these require a more plastic mixture and the lime makes it work a little smoother. There is now, however, a tendency among manufacturers to secure an

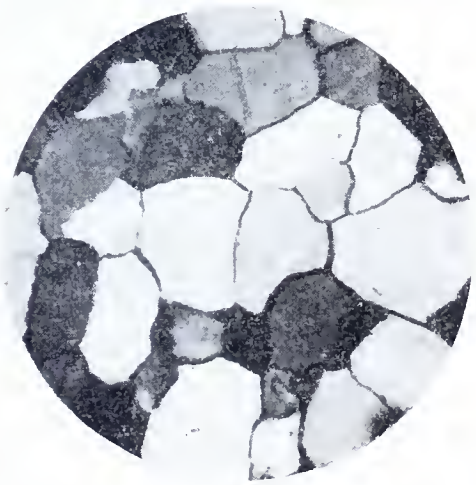
PLATE XIV



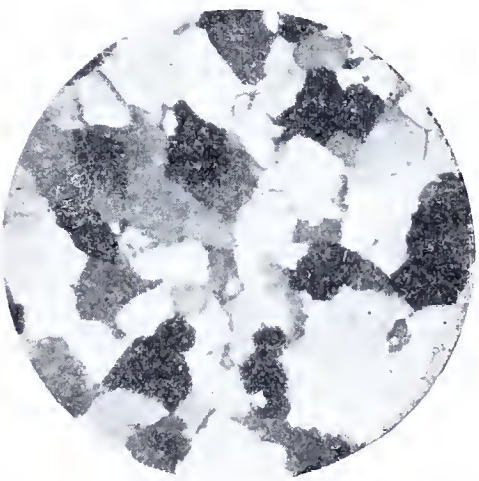
A. Photomicrograph of a first-class well bonded silica brick. The white fragments are quartz, some of which are partly altered to tridymite. The matrix consists of quartz, silicates, tridymite, and cristobalite. (X60)



B. Photomicrograph of weak, discolored brick showing a large quantity of iron oxide in the bond not properly combined with silica and lime. (X60)



C. Photomicrograph of typical high grade glass sand rock from the Oriskany formation at Mapleton Huntingdon County. When the rock is crushed the grains readily separate from each other without fracturing. (X60)



D. Photomicrograph showing the dense, thoroughly cemented character of typical Tuscarora quarzite used in the manufacture of silica brick. In contrast to glass sand rock the cementing material does not fracture more readily than the quartz grains. (X60)

easier working mixture by finer grinding instead of by increasing the lime content because the increase in lime lowers the fusion point and decreases the strength of the bond. Kenneth Seaver,[5] chief engineer of the Harbison-Walker Refractories Company, has drawn the following conclusions regarding the effect of lime: Below 1.5 per cent of lime there is a decrease in strength and as the lime content is decreased still further the brick becomes markedly weaker and more friable. On the other hand, there is little difference observed in the properties of the brick when the lime is increased from 2 to 3 per cent, beyond the fact that it is slightly less resistant to abrasion. In an increase of lime from 3 to 7 per cent there is a progressive and accelerated decrease in strength. While no apparent decrease in refractoriness occurs with an increase in lime up to 3 per cent, above that point there is a growing reduction with each addition of lime.

Calcium in the form of calcium carbonate is objectionable in the raw material because, in burning the brick, this compound breaks down to lime and carbon dioxide is given off, causing the brick to crumble if there be much gas present.

Effect of alumina. Alumina, in the form of clay, is now regarded as one of the most objectionable constituents in silica brick. It is probable that the iron oxide has in many cases been held responsible for the failure of brick when alumina was the main cause, as it seems to be much the more objectionable of the two constituents. It occurs in the quarries in thin streaks, in nests or spots and in handling the rock it collects in the hoppers of the crushers and especially in the bins. Care must be exercised to prevent any considerable quantity entering the pans at one time. Sometimes in cleaning the bins for crushed rock a large amount of clay gets into the mixture and spoils a batch of brick. Some operators have complained that there is more trouble with aluminous material in the winter than in the summer. This might be accounted for by the clay freezing to the quartzite and not sifting out with handling as it would when drier.

Since the alumina is in the softer and finer ground material there will be more of it in the finer material coming from the crushers and pans. It is to a considerable degree in the weathering out of the clay that the talus or "floe rock" possesses properties superior to the ledge rock from which it is derived. Some operators have endeavored to loosen up the clay seams by letting the rock lie exposed to the weather after quarrying. This, however, is a slow process and while even a short period of weathering helps, it means

[5]Seaver, Kenneth, Manufacture and tests of silica brick for the by-products coke oven: Trans. Amer. Inst. Mining and Met. Eng., vol. LIII, p. 125, 1915.

extra handling and delay in operations. The question, therefore, arises as to whether the rock could be washed profitably. Washing after crushing would undoubtedly remove the greater part of the alumina, and it is the writer's opinion that in the future, when high grade raw materials become scarcer, much of the rock will be washed after crushing.

The presence of alumina in a brick undoubtedly lowers the fusion point and also prevents a satisfactory bonding of the silica by the lime. Whether its presence in a clay coating on the grains of silica prevents a proper action between the lime bond and the silica is not certain. The bricks which contain more than the normal amount are poorly bonded and break easily. The effect of alumina on the fusibility of the quartzite used in the manufacture of silica brick is well illustrated by the accompanying chart (Fig. 8) which shows the relation of the fusion point of quartzite to the percentage of alumina in over 60 samples. There are many variations in the curve due to factors other than the alumina but in its broader features it shows a very definite decrease in the temperature of fusibility with an increase in alumina.

Effect of iron. There is much difference of opinion among operators as to the effect of iron on brick. It was found in discussing this matter with the men engaged in the manufacture of brick that 2 per cent should be regarded as the maximum for the average rock, although some have placed it as low as 1 per cent and one brick manufacturer as high as 7 per cent. The writer feels that this is much too high, even though some brick have been made containing as high a percentage of iron. The form in which the iron occurs will have some influence. Magnetite (Fe_3O_4) which will stand a high temperature would not have as much effect on the brick as hematite (Fe_2O_3) and far less than limonite the hydrous oxide, ($2Fe_2O_3.3H_2O$) or siderite the carbonate ($FeCo_3$). All these forms occur in the rock in small quantities. The iron seems, as a rule, to strengthen the bond in the brick but it lowers the fusibility.

The accompanying chart (Fig. 9) shows the general effect of iron oxide in lowering the fusibility of quartzite. In the two charts showing the relation between alumina, iron oxide, and fusibility it may be observed that there is a drop of 0.71° C. in fusibility for an increase of 0.01 per cent in the iron content between the maximum and minimum percentages of iron oxide in the samples, whereas there is a drop of 1.7° C. in fusion point for an increase of 0.01 per cent in alumina between the maximum and minimum percentages of alumina in the samples. These interpretations must not be

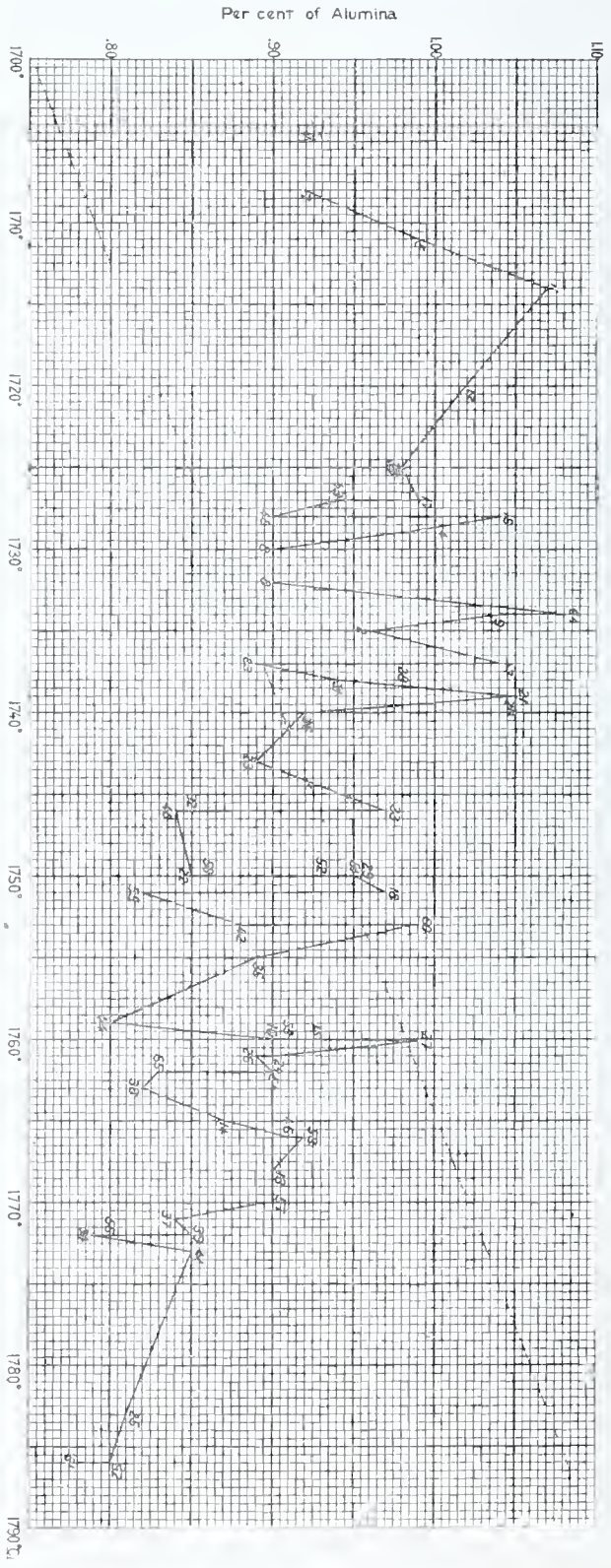


Fig. 8. Effect of alumina on fusibility.

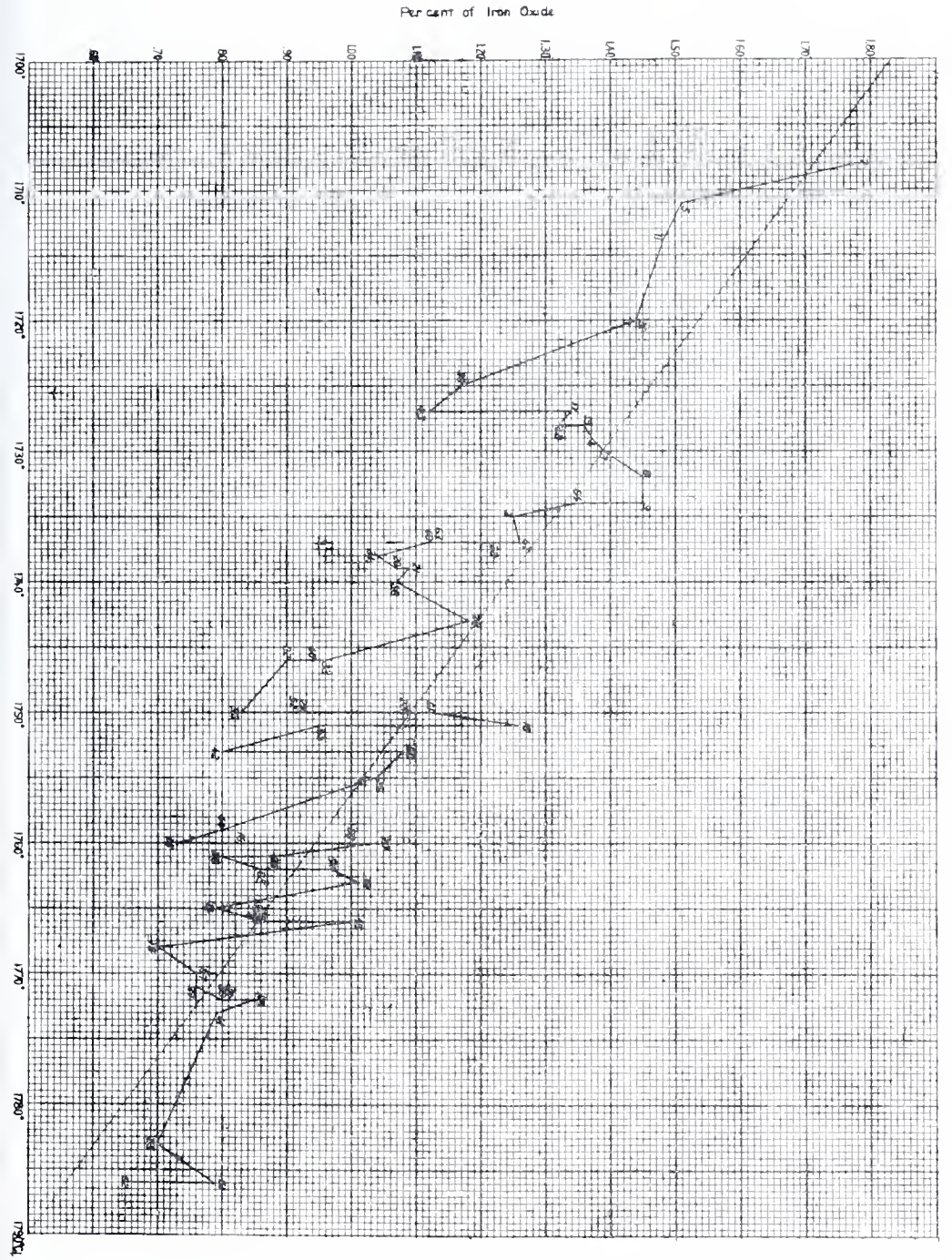


Fig. 9. Effect of iron oxide on fusibility.

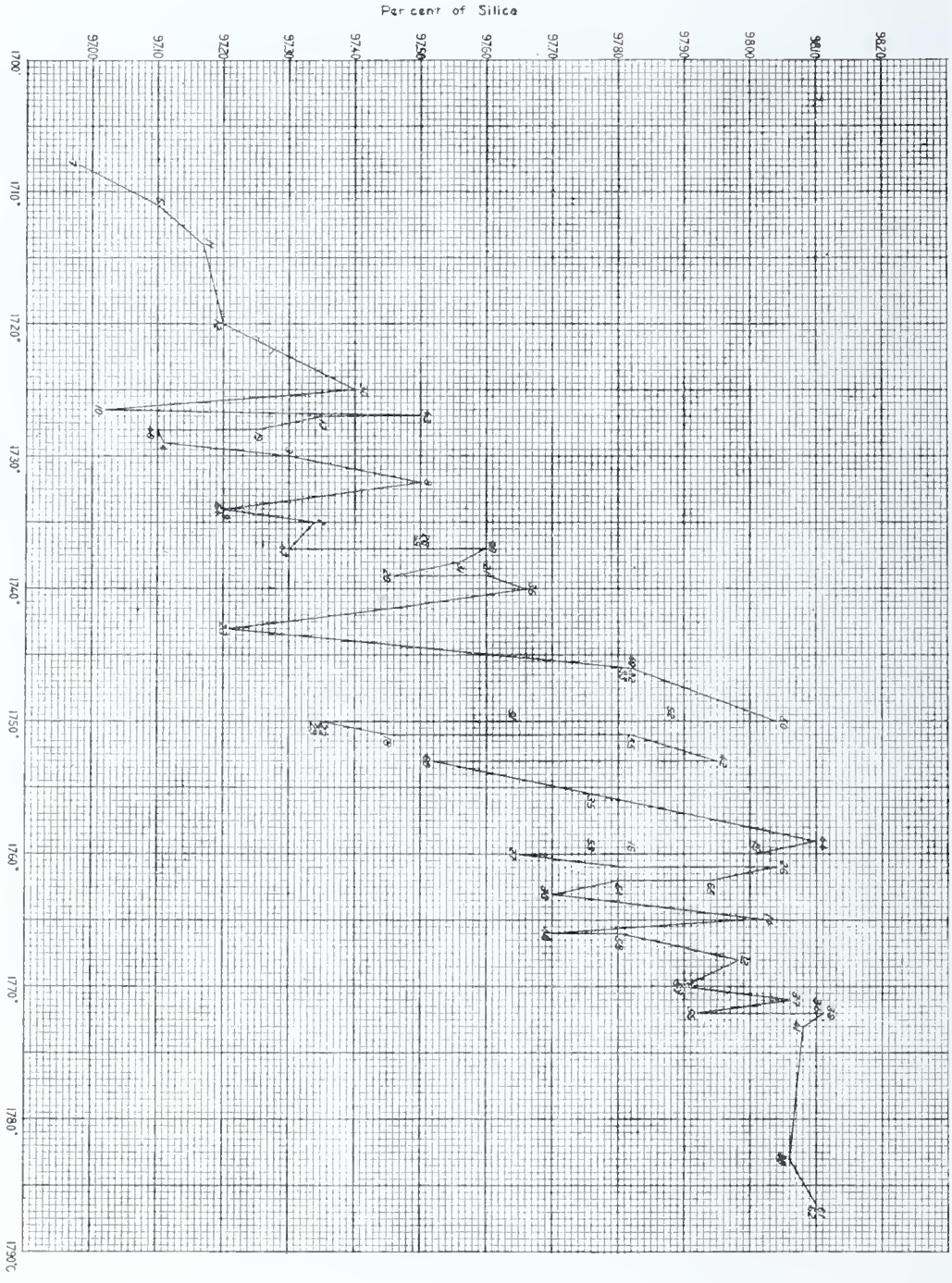


Fig. 10. Effect of silica on fusibility.

applied rigidly because some other factors enter into the consideration. Where there is clay there is present, doubtless, a certain additional amount of alkalies, especially potash. The potash commonly occurs in muscovite, the colorless mica, or it may be absorbed in the clay. There is evidence also that there is some serpentine and talc in some of the cracks in the quartzite, adding magnesia to the clay streaks. As a rule, more iron and calcium will be found in objectionable quantities in the clay seams than in other portions of the rock although iron and calcium are in most cases carried in solution so that they permeate smaller openings in the quartzite than the aluminous materials in the form of clay can enter in appreciable quantities.

Effect of silica. Since silica is the main refractory substance in the brick it is not necessary to discuss at length its refractory influence. The accompanying chart (Fig. 10) shows that in a general way there is a direct relation between the silica content and the fusibility. Other factors being equal, the silica content should directly control the fusibility, although not all the properties of the brick, because the physical properties of the silica play an important role in the development of a good brick and silica may have varying physical properties without a variation in chemical properties. A quartzite is required for the manufacture of silica brick. Two rocks may be equally pure and very high in silica and one will make good silica brick and the other will not. A rock which makes the best glass sand is quite unsuited for silica brick because a good glass sand rock when crushed readily crumbles and the individual sand grains separate from one another. A good silica brick rock, on the other hand, is hard to crush and when it is crushed the quartz grains are broken. The grains are bound together by a firm silica bond which is just as strong as the grains themselves. The quartzite probably furnishes a more refractory material than the glass sand rock because when it is crushed some larger fragments of quartz remain and these change more gradually to tridymite and cristobalite than finer grains do, thus preventing a sudden softening of the whole mass of the brick. Plate XIV, C and D show the main physical differences between a high grade glass sand rock and good quartzite for silica brick.

Vein quartz, chert, chalcedony or amorphous silica, such as opal, cannot be used as ganister or in the manufacture of silica brick because, on the application of heat, these materials decrepitate and crumble to powder.

An increase in silica just decreases to that extent the possibility of injurious impurities being present. A reasonable proportion of impurities is, however, necessary for the proper bonding of the brick since they serve as a flux in the transformation of the quartz into tridymite and cristobalite during the firing. Le Chatelier and Bogitch[6] consider that there should be not less than 1.5 per cent of the basic oxides present and that two per cent of these represents a good working average.

Effect of other impurities. The alkalies greatly affect the fusibility, reducing the fusion point rapidly. They exert a strong solvent action on the silica, especially the tridymite network. At the same time they serve as a flux in the process of transforming the quartz into the other forms of silica. Magnesia tends to lower the fusion point and titanium has a marked influence in the same direction. The amount of titanic acid in most of the brick made in Pennsylvania is very small. Titanium occurs in grains of titanite or sphene and in rutile but in small amounts.

PHYSICAL PROPERTIES OF SILICA BRICK.[7]

The physical properties of silica brick are to a large extent those of quartz which has been subjected to high temperatures. Therefore a discussion of the properties of quartz and the changes which take place in those properties on burning to brick is essential to an understanding of the properties possessed by brick. The physical property which makes silica brick so valuable in the industries is that of mechanical strength at high temperatures. A silica brick remains rigid until the temperature of fusion is almost reached.

Various forms of silica. When silica brick is burned under normal conditions it expands about 3/8 of an inch per foot due to the transformation of the silica in the quartzite to another form. The three allotropic forms in which silica exists in the brick under different conditions are quartz, tridymite, and cristobalite. Each of these forms has an alpha and beta phase and, according to Fenner of the Carnegie Geophysical Laboratory, the temperature at which these different phase forms and phases exist are as follows:

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[6]LeChatelier, H. and Bogitch, B., The manufacture of silica brick: Trans. Amer. Inst. Min. and Met. Eng., vol. LX., pp. 134-161, 1919.

[7]For excellent papers summarizing the data on this subject see: McDowell, J. Spotts, A study of the silica refractories: Trans. Amer. Inst. Min. Eng., vol. LVII, pp. 3-59, 1917. LeChatelier, H. and Bogitch, B., The manufacture of silica brick: Trans. Amer. Inst. Min and Met. Eng. vol. LX, pp. 134-161, 1919.

[8]Fenner, Clarenee N., Stability relations of silica minerals: Amer. Jour. Sci 4th ser. vol. 36, pp. 331-384, 1913.

α-quartz $\rightleftarrows$ β quartz, 575°C.
β-quartz $\rightleftarrows$ α-quartz, 570°C.

α-tridymite $\rightleftarrows$ β_1-tridymite, 117°C.
β_1-tridymite $\rightleftarrows$ β_2-tridymite, 163°C.
Reversions on cooling not very sharp.

α-cristobalite $\rightleftarrows$ β-cristobalite, 274.6° to 219.7°C., depending upon previous heat treatment.

β-cristobalite $\rightleftarrows$ α-cristobalite, 240.5° to 198.1°C., depending upon previous heat treatment.

The remarkable variations in the temperature of inversion of α-cristobalite into β-cristobalite led Fenner to regard this mineral as being made up of two different molecular species of silica within the same crystal. At ordinary temperatures only the α phase of each mineral exists and the β phase results from heating of the α phase.

At 870°C. $\pm$ 10° quartz $\rightleftarrows$ tridymite.

At 1470° $\pm$ 10° tridymite $\rightleftarrows$ cristobalite.

In all these inversions the change from the α phase to the β phase is rapid but the change from one form to another is much slower. The important fact to be borne in mind is that the change from quartz to tridymite or vice versa, does not take place except in the presence of a flux. Prolonged heating has an effect on the amount of change which takes place in a brick, for example, but the presence of a flux is the fundamental factor. If quartz be heated without a flux it does not change into tridymite at 870°C. but at about 1250°C. it begins to change directly to cristobalite. The temperature of formation of cristobalite from quartz is, therefore, lower than that for the formation of cristobalite from tridymite. It is the lack of a flux which permits the existence of the high temperature forms at ordinary temperatures. When once formed it is impossible for them to revert without the aid of such an agent. Between 870° and 1470° tridymite always forms when a tungstate melt is used as a flux and from 1300° upward the reaction is rapid. Further, any form of silica, heated with such a melt between 1470° and the melting point of cristobalite, changes to cristobalite and from 1500° upward the change is fairly rapid. Fine grinding increases the rate of reaction.

Apparently cristobalite may be formed from both quartz and tridymite without the aid of a flux. Tridymite changes to cristobalite at 1370° and, as previously stated, quartz begins to change over at 1250°C. Amorphous silica without a flux changes to cristobalite without the intervening form, tridymite, developing. If amorphous silica be heated without a flux, at any temperature below the melting point of cristobalite, it changes to cristobalite at a rate depending upon the temperature. In an experiment by Fenner precipitated silica appeared to be completely changed to cristobalite after 69 hours heating at 1030°C. $\pm$

In a microscopic study of calcined quartz or burned silica brick the various forms of silica may be recognized by the following properties: Since only the α phases of the various forms exist at ordinary temperatures it is not necessary to discuss the β phase: Quartz crystallizes in the hexagonal system, it is trapezohedral-tetartohedral and its habit is pyramidal. Its index of refraction is 1.544 for α and 1.553 for γ, its optical character is positive. The cleavage is indistinct and the fracture conchoidal. Tridymite is orthorhombic and its crystal habit thin pseudohexagonal plates or columnar crystals in aggregates of needles. It is optically positive and its index is 1.469 for α and 1.473 for γ. It is colorless. At ordinary temperatures cristobalite is probably tetragonal but it becomes isometric on heating to the β phase. It differs from quartz and tridymite in being optically negative. Its birefringence is very low, the mean index being 1.432 and for $\omega - \epsilon$ 0.00053. The compound occurs as grains with very marked conchoidal fracture.

Of the optical properties the index of refraction is probably the most useful determinative factor in identifying the different forms of silica in a brick. The material to be studied may be crushed and examined in liquids having indices of refraction lying between those of the forms of silica it is desired to separate. The different forms of silica may also be separated on the stage of the microscope by applying the Becke method to powder or thin sections.

Endell has adopted the method of placing over a photomicrograph of a section of brick a grating of transparent paper on which he pricks the quartz and silicates. The tridymite, which is usually less than 5 per cent, is calculated and the cristobalite determined by difference. The quartz and silicates are recognized by higher indices of refraction and higher birefringence. He claims that this method is exact to within 2 per cent.[9]

The percentages of the various forms of silica in burned bricks according to several investigators are as follows:

	Quartz and silicates	Tridymite	Cristobalite
Endell	10-40	1-5	46-85
Seaver	14-51	.....	48-86
McDowell	12-40	1-45*	42-71

*This is for brick burned six times. Repeated burning produces more tridymite than a single burning.

Expansion in silica brick. It is evident that when quartz changes to tridymite or cristobalite a permanent change in volume must occur in addition to the ordinary thermal expansion similar to that suffered by practically all other objects when heated. The densities of the three different forms of silica are as follows: quartz, 2.65; tridymite, 2.27; and cristobalite, 2.33. The volume increase in a change from quartz to cristobalite is 13.6 per cent and from quartz to tridymite 16.8 per cent and the permanent expansion in the brick from burning will therefore depend upon the relative amounts of quartz, tridymite, and cristobalite in the burned brick. These proportions will depend upon the temperature and rate of burning and

[9]Endell, K. H., The testing of silica brick: Jour Amer. Ceramic Soc. vol. V. p. 215, 1922.

upon the amount and nature of the flux present since their specific volume will vary from that of the different forms of silica. They affect the amount of inversion which takes place and consequently the percentage of the various forms of silica.

According to McDowell[10] the average permanent linear expansion for a silica brick is about 3/8 to 7/16 inch per foot which is equivalent to 3.1 to 3.6 per cent. The linear expansion in the case of complete transformation from quartz to tridymite would be 5.3 per cent and from quartz to cristobalite 4.35 per cent. The thermal expansion of well-burned brick is about 3/16 to 1/4 inch per foot or 1.6 to 2.1 per cent. Of this expansion the greater part occurs below 600°C. Tridymite suffers less thermal expansion than quartz or cristobalite and it is therefore an advantage to have a sufficient proportion of it in a brick.

It is necessary to allow for this large amount of expansion in laying silica brick in a furnace or oven, and it is customary to place cardboard between the bricks in order that as they heat up and the cardboard is burned out they will close up the intervening space. Very often open expansion joints are left in the roof, without any filling of cardboard or wooden strips. The amount of space left, according to Hofman[11], is about ¼ inch per foot where 12-inch brick are used in the roof of copper reverberatory furnaces and 5/16 inches to each 2 feet in the bottom. The mortar used is a slurry of finely ground fire-sand and fire-clay in the proportion of 60:40.

The amount of permanent expansion is greatly influenced by the time and temperature of burning. Rapid heating may, according to LeChatelier and Bogitch[12], increase the expansion three to six times that caused by slow heating. This is due to the opening up of numerous minute cracks which weaken the brick very much and such a method of heating should be carefully avoided. By careful firing the expansion can be greatly reduced and a much stronger brick obtained. The expansion which always occurs after silica brick are placed in a furnace and subjected to high temperature is due to the further transformation of the silica into different forms. Time and temperature are the main factors in producing the transformation and a brick which has been in a furnace for some months shows a marked difference in the proportions of quartz, tridymite, and cristobalite from those present when the brick was taken from the kiln. It is desirable to have the expansion developed to as high a degree as possible in the kiln.

Fusibility. The fusibility of a silica brick will depend to a considerable degree upon the relative percentages of the different forms

[10]McDowell, J. Spotts, op. cit. p. 25.
[11]Hofman, H. O., General matallurgy: McGraw-Hill Book Co., N. Y. p. 368. 1913.
[12]LeChatelier, H. and Bogitch, B., op cit., p. 148.

of silica which compose it and especially upon the percentage of fluxes which it contains. In metallurgical practice it is found that fusibility is also dependent to some degree upon the pressure in the furnaces. Experiments of various investigators have shown that the melting point for silica brick lies between 1700° and 1800°C., or the brick becomes viscous above 1700°C*. Bricks in a furnace or oven will, as a rule, stand higher temperatures than those tested in the laboratory, providing the pressures in the two cases are equal, because only a small portion of the brick is at any time exposed to the maximum temperature of the furnace.

Crushing strength. The determination of crushing strength of refractory brick should be made at high temperatures if it is to be of any practical value because it is at high temperatures that such brick fail under pressure, in practice. The following conclusions may be drawn from the excellent results secured by McDowell[13] in a large number of tests which were conducted under varying conditions: The fineness of the grind, the temperature at which the brick is burned, and the number of times it is burned** all influence the strength of the brick. If a brick is burned only once it is stronger if burned at cone 15 than at cone 13 or 14. A second burning strengthens the brick of all grinds, whereas a third burning may or may not strengthen it. Bricks of regular grind, or in other words, those made from material ground as it would be for the ordinary 9-inch brick, increase in strength for three burns. They should be burned at a temperature not less than cone 15. The increase for three burns is apparently due to the larger quartz fragments requiring a higher temperature than the smaller fragments to transform them into tridymite. For bricks of fine grind the second burn should be at cone 14 and for those of medium grind at cone 14 or 15. Uniformity in strength grows less in a given lot of brick with repeated burning. They are weakened a little in compressive strength and considerably in cross-breaking strength. Those of regular grind are most uniform while those of fine grind are fairly uniform in crushing strength but they lack uniformity in cross-breaking strength. In cross-breaking those of fine grind are little better than those of regular grind. Their mean strength is high but it is not uniform. It is much higher than that of the bricks of regular grind. On account of the development of minute cracks during repeated burning, McDowell suggests longer burning instead of repeated burning as a means of securing greater strength.

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[13]McDowell, J. Spotts, op. cit., p. 37.

*C. W. Kanolt determined the fusion point of silica brick as 1700°-1705°C. (U. S. Bur. Standards Tech. Paper No. 10).

**Commercially, of course, brick are burned only once.

The results of these tests are summarized in the following table:

Cross-breaking and crushing tests on silica brick, by McDowell.

No. of burns	Cone	Modulus of rupture, brick tested edgewise, 6-inch span.						Crushing strength, brick laid flat.					
		Regular grind		Medium grind		Fine grind		Regular grind		Medium grind		Fine grind	
		Mean	a.d.	Mean	a.d.	Mean	a.d.	Mean	a.d.	Mean	a.d.	Mean	a.d.
1	15	920	3	1,050	6	1,170	19	2,080	6	4,780	14	5,880	17
	14	770	5	920	11	790	52	2,100	3	4,820	7	5,250	3
	13	690	10	910	24	910	6	2,730	8	4,680	11	5,840	6
2	15–15	910	15	1,680	5	1,270	43	2,080	9	6,060	11	6,890	14
	14–14	920	3	1,680	7	1,590	24	2,680	5	5,570	5	7,830	6
	13–13	1,010	10	1,310	24	1,070	13	2,760	5	6,270	11	6,290	12
3	15–15–15	1,200	25	1,210	25	1,240	28	3,140	5	6,550	3	7,060	9
	14–14–15	1,110	7	1,580	16	680	38	2,490	11	4,870	7	6,660	11
	13–13–15	1,010	20	1,320	43	1,730	17	2,850	6	6,380	17	8,110	9

Regular grind is that of the regular 9 inch brick pounded into loose side molds.
Medium grind is that of shapes pounded into loose side molds.
Fine grind; 71 per cent passed a 40 mesh screen whereas 64.8 per cent of the medium and 56.5 of the regular grind passed the same screen.
The brick were burned approximately 10 days each time they were burned.
a. d. represents the average deviation in per cent of mean.

In the series of tests made by Howe and Kerr[14] it was found that 17 standard brands of commercial silica brick possessed moduli of rupture varying from 401 to 921 pounds to the square inch. They also found that the fineness of grinding and the duration of burning had an important influence on the modulus of rupture. The samples were ground for 10, 15 or 20 minute periods for the different tests and then burned at cones ranging from 11 to 19. The results showed that the average modulus of ruptures for all grinds, at these different cones was 303, 368, 444, 572, 533, and 514 pounds per square inch respectively, and the average for each grind at all cones was 440, 446, and 499 pounds respectively for the 10, 15, and 20-minute grinds. The increase in strength did not take place uniformly with increase in temperature except that all three grinds showed a higher strength after burning at cone 19 than at any other cone.

In a series of load tests at high temperatures Endell[15] found that German silica brick made for the by-product coke oven and glass furnace, ruptured at temperatures running from 1600 to 1620°C. under a load of 1 kg. per sq. cm. The higher quality brick made by the large steel works ran 1605 to 1670°C. under the same load. Under the same conditions Star brand brick from "Medina" quartzite of Pennsylvania reached 1620° before rupturing. Bricks from English ganister reached 1660° and those from Swedish quartzite 1620 to 1650°. These tests were made in the standard lever press

[14]Howe, R. M. and Kerr, W. R. Burn on the characteristics of silica brick: Jour. Amer. Ceramic Soc., vol. V, p. 164, 1922.
[15]Endell, K. H. op. cit. p. 216.

furnace. Other tests were made in the Steger lever press, carbon resistance, electric furnace fitted with optical pyrometer. Specimens were heated for 1½ hours to 1600°C. With this furnace the softening temperature was determined and it was found that with a load of 1 kilogram per square centimeter, German basic open hearth furnace and by-product coke oven brick softened at temperatures running from 1455° to 1555°C. The test cylinders used in the furnace were 50 mm. in diameter and 50 mm. high. They were cut from standard bricks with a diamond drill cylinder. The ends were ground and polished smooth. Although this removes the exterior coat of the brick it gives uniformity in the material used. Some test cylinders were made by filling soft steel rings with raw material and burning them at 1450°C. in a porcelain furnace.

The following are the tentative specifications of the American Society for Testing Materials for tests of refractory materials under load, at high temperatures[16]. The furnace is cylindrical in form and 14 inches in internal diameter. Heating is done by gas or oil fuel with compressed air blast. The burners are to be not less than two and they are placed tangentially in such a position that the flame does not impinge on the specimen being tested. The temperature may be measured with a platinum-rhodium thermo-couple encased in a double protecting tube with the junction not more than 1 inch (25mm.) from the center; or with some form of optical pyrometer that has been calibrated against a thermo-conple in the furnace.

The load is applied by means of a calibrated lever system and it shall be at least 25 pounds per square inch (1.765 kgm. per sq. cm.).

The test specimen shall consist, whenever possible, of a standard 9-inch brick placed vertically on end. In cases where shapes and blocks are tested the specimen shall be approximately 9 x 4½ x 2½ inches (228 x 114 x 64mm.) being cut from the sample so as to preserve as far as possible the existing plane surfaces. A cut specimen shall be grounnd or held in cement so that it will rest in a position normal to the bottom of the furnace. It shall rest on a highly refractory block in the center of the furnace. Silica-carbide brick has been found satisfactory for this purpose. On top of the specimen shall be placed a bar of material similar to that which lies underneath it and this shall extend above the top of the furnace to receive the load. Before being placed in the furnace the specimen shall be measured not less than 5 times in each direction and until the results do not vary more than 0.02 inch (0.5mm.).

The temperatures for heating silica materials for various periods are as follows: 1 hour at 200°C., 2 hours at 500°C., 3 hours at 900°C., 4 hours at 1350°C., 6 hours at 1500°C. (End of test).

[16]American Society for Testing Materials Standards: vol. XVII, p. 665, 1917.

At the end of the heating period, the heat is turned off and the furnace is allowed to cool during a minimum of 5 hours before the load is removed. After cooling to room temperature the specimen is again accurately measured and the change recorded.

Endell considers that the tests for crushing strength adopted in the United States are not severe enough and that the temperature should be raised to 1600°C. with the pressure placed at 1 kg. per square centimeter—approximately 15 pounds to the square inch—as these standards are much nearer those of practical conditions than those generally employed.

A large number of tests on brick at high temperatures have been made by LeChatelier and Bogitch[18]. The tests were made in a small furnace heated by illuminating gas. The furnace reached 1600°C. in half an hour of firing with blast. The walls of the furnace were made of fused bauxite, or corindite, cemented with a small amount of sodium silicate, an excellent heat resister when not supporting any load. Pressure was applied through a bauxite cylinder which had been previously calcined at 1600°C. The samples as cut had axes 3 cm. long. The temperatures were taken by means of an electric thermo-couple attached to the sample. The following table is valuable as showing the relative crushing strength of various substances at high temperatures.

Crushing strength of bricks at different temperatures (°C.) in kgs. per sq. cm.

	15°	500°	1000°	1300°	1400°	1500°	1600°
Silica (Star brand)	170	150	120	75	60	48	30
Euobean magnesite	420	380	320	270	240	(185)	(8)
Kaolin	190	180	210	90	(12)	(1)	(0.5)
Euobean magnesite	420	380	320	270	240	(135)	(8)
Styrian magnesite	145	130	85	66	(5)	(3)	(1)

These writers found that the silica brick broke abruptly at all temperatures, whereas the clay and magnesia brick failed gradually as slightly plastic bodies above 1000° and at temperatures depending upon the purity of the material. Complete viscosity of the silica brick was attained above 1700° C. These brick stand a temperature considerably higher than this in a furnace because only one surface is fully exposed to the highest temperature of the furnace. A large number of tests by these writers furnished the following data:

[18]Op. cit. p. 145.

Table showing features of certain silica brick

Mark	Quality	Sulphate per cent	Density		Crushing strength		
			Absolute	Apparent	Temp. °C	Time: Minutes	Kg. per sq. cm.
Assailly	Very good	13.6	2.30	1.92	15		550
Assailly	Very good				1600	60	90
Star	Very good	9.06	2.33	1.66	15		170
Star					1600	5	33
Star					1600	60	30
GI	Very good	8.40	2.33	1.88	15		185
GI					1600	60	41
R. B.	Very good	13.10	2.35	1.60	15		62
R. B.					1600	60	9.5
R. L.	Very good	14.3	2.40	1.85	15		265
R. L.					1600	5	41
R. L.					1600	60	25
G. A.	Good	14.0	2.40	1.77	15		190
G. A.					1600	60	21
D	Good	8.4	2.45	1.73	15		320
D					1600	5	55
D					1600	60	20
G A^1	Very bad	14.5	2.46	1.80	15		252
G A^1					1600	60	4.4
R. F.	Very good	13.7	2.48	1.84	15		195
R. F.					1600		11
G A^2	Very bad	12.8	2.48	1.78	15		148
G A^2					1600	60	5
G. M.	Medium	9.5	2.53	1.84	15		84
G. M.					1600	5	17
G. M.					1600	60	2
R. L.	Bad	9.75	2.56	1.94	15		350
R. L.	Shatters				1600	5	18
R. L.					1600	60	4.5
R. S. G.	Bad	25.0	2.56	1.73	15		57
R. S. G.	(Melted)				1550	60	22
R. S. G.					1600	melted	----

These tests were made on brands of brick which had been tried out by the French steel companies. The Assailly brand had stood a year in the lining of the outlet of a gas producer. The American Star brand and G. I., a French brick, had been highly recommended, whereas the R. S. G. brand was so poor that it melted on the first application of heat. The other brands were manufactured in France, England and Germany. All the good bricks showed a compressive strength above 10 kg. per square centimeter after being held at 1600°C. for one hour and most of the good ones exceeded 20 kg., whereas the strength of the inferior bricks was below 5 kg. Most good bricks have densities below 2.40 and the amount of sulphate in them is below 15 per cent. This percentage of sulphate is the equivalent in sulphate of the basic oxides.

Density and porosity. As indicated in the tables given above the true specific gravity of silica brick varies from 2.30 to 2.56. The gravity of the best bricks seems to lie between 2.30 and 2.40. Endell states that they should test at least 2.38. The apparent specific gravity lies between 1.65 and 1.95. The specific gravity of a quartz is 2.65; of tridymite, 2.27; and of cristobalite, 2.33; therefore the

specific gravity of the brick will depend to some extent upon the relative proportions of these constituents. There is no definite relation between the porosity and the true specific gravity because the true specific gravity is the specific gravity of the silica substance of the brick. The relative porosity greatly affects the apparent specific gravity which is the specific gravity of the brick, including pores. The apparent specific gravity is considerably affected by burning and but little affected by the fineness of grind of the raw material. Repeated burning or burning at higher temperatures reduces the specific gravity, as shown by Howe and Kerr[19], independently of the grind. The porosity is affected in a non-uniform manner by burning. This seems to be due to the opening of minute cracks. The amount of permanent expansion shows a fairly definite relation to the true specific gravity.

To determine the true specific gravity, Messrs. Harvey and Magee have adopted the method of boiling the sample for 1½ hours under a vacuum of at least 20 inches of mercury, whereas Endell considers that the best way of determining the specific gravity is by means of the small pycnometer of 3 c. c. capacity, with finely powdered material. The pycnometer method is the one generally adopted.

The density of silica brick is a more important consideration in glass manufacture than the fusibility because of the absorption. In metallurgical practice the density has an influence upon the rate of transfer of heat because of the permeability of gas. Porosity is determined by the relative absorption of water by the brick. It runs from about 20 to 40 per cent, 25 to 30 per cent being common limits.

Thermal conductivity. Thermal conductivity is measured by the determination of the flow of heat in calories per second, through an area of one square centimeter, one centimeter in thickness when the temperature difference on the opposite sides of the layer one centimeter thick, is 1° C. This coefficient is designated as k. The various tests made indicate that silica brick has slightly higher thermal conductivity than fire clay brick or "quartzite" brick. Further, like clay brick, the conductivity of silica brick increases with a rise in temperature but it increases slightly more rapidly in silica brick with increase in temperature than it does in fire clay brick. The experiments of Dudley[20] indicate that the conductivity of several refractory bricks is as follows:

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[19]Howe, R. M. and Kerr, W. R., Influence of grind and burn on the characteristics of silica brick: Jour Amer. Cer. Soc., vol. 5, No. 4, p. 166, 1922.

[20]Dudley, Boyd Jr., Thermal conductivity of refractories: Penn. State College Bull. vol. XI No. 16, 1917. This work contains bibliography and summary of the results secured by various writers.

Conductivity of Harbison-Walker bricks in G calories per second, per cubic inch, per degree centigrade.

Materials	Conductivity At 100°C	At 1000°C.
Woodland first quality, an all fire clay brick	0.0043	0.0086
Quartzite brick, a silica brick with clay bond	0.0051	0.0086
Star silica brick, with lime bond, ...	0.0056	0.0108
Dead burned magnesite brick		0.034

Of the high grade refractories, silica brick has very low thermal conductivity. Graphite brick conducts over 12 times, carborundum over 11 times, and ordinary building brick about one and one-half times as readily as silica brick.

Specific heat. The specific heat of most silica brick ranges from 0.200 at 0° to 0.291 at 1200° C.

Spalling. There is a close relation between the cross-breaking strength and the spalling tendency in silica brick. When a brick is heated quickly and allowed to cool it loses a large percentage of its strength because of the innumerable small cracks developed in it. According to LeChatelier and Bogitch,[21] heating quickly through a temperature of 225° C. is sure to produce these cracks and weaken the brick. Silica brick should, therefore, not be used where frequent and rapid changes in temperature occur. These writers recommend heating up at the rate of about 50° per hour and allowing cooling at the same rate, thus avoiding all such cracking. It is evident, therefore, that wood fires for starting furnace heats are bad. McDowell has found that heat treatment by reburning reduces the spalling tendency to a considerable degree by reducing the cristobalite and increasing the tridymite. He does not consider this of much commercial value, however.

MANUFACTURE OF SILICA BRICK IN PENNSYLVANIA.

Crushing.

Rock received from the quarry is passed, first, through a crusher which breaks it into pieces about egg size, or, as usually described about 1½ to 2 inches in diameter. In practically all cases this crushed rock is passed on to the wet pans without other treatment, but at one plant the crushed rock is screened to remove the fines, which carry most of the clay impurities. The fines are then added to the mixture in the pan in proper proportion and of correct composition to produce the best results in brick making.

[21] Op. cit., p. 148.

The crusher used in most plants in Pennsylvania is the Champion 5x type, manufactured by the Good Roads Machinery Company. The Champion No. 6 was found in one plant. Several Farrel crushers (Style B) are in use. In one plant a large Kennedy No. 7½ gyratory crusher is used for preliminary crushing of large blocks. The jaw crusher, of which the Champion and Farrel are types, is almost universally adopted for crushing the quartzite, because the wear on a gyratory machine in breaking the hard rock seems to be excessive. The jaw crusher also furnishes the desired size of crushed rock more readily than a gyratory machine. The Harbison-Walker Refractories Company redesigned a Champion crusher for their plant at Mount Union with a stronger, solid steel frame. It stands the heavy duty demanded of it better than the ordinary type of machine.

Those companies crushing quartzite for ballast as well as for ganister and related purposes, screen the rock. Some operators have stated that the plants purchasing rock for ferro-silicon prefer that it be in blocks approximately uniform in size, but no standards of size seem to be fixed. Crushing is done at the brick plant by practically all companies. One company crushes at the quarry and transports the crushed rock to the brick plant by an aerial tram. The main advantages claimed for crushing at the quarry are in the elimination of dust and noise and a certain amount of waste rock from the brick plant.

Grinding and mixing.

Quartzite for silica brick is invariably ground in wet pans of the Clearfield type. These pans are 8 feet in diameter and are over or under-driven. Some have 60 h. p. individual motors. The rollers weigh about 5 tons and are about 5 feet in diameter. The crushed rock is fed into the pans in weighed charges. Some machines are equipped with automatic gates for feeding the charge into the pan; the gates on others are operated by hand.

About 3 tons of crushed rock are required to make 1000 brick of 9-inch equivalent. In some plants up to 10 per cent of brick bats (some authorities recommend even more) is used in the charge for the purpose of strengthening the brick and reducing expansion. The added strength comes apparently from the development of a greater proportion of tridymite on second burning of the crushed brick. The length of time required to grind a pan of rock varies with the type of brick which is to be made from the charge. It was formerly the custom to secure the easier working of the mixture used in making shapes by increasing the lime at the expense of strength, but it has been found that better results are obtained by longer and

finer grinding than by increasing the lime in the bond. For ordinary 9-inch brick a pan is usually ground 12 to 15 minutes. The operator judges the quality of the mixture by its feel to the hand. For shapes the grinding is continued much longer, even to 30 minutes, depending upon the difficulty of molding them.

The proper proportions of coarse and fine material should always be maintained, not only because finer grinding makes the mixture work smoother but because the fine material facilitates the transformation of the quartz into tridymite and makes thereby a stronger brick. Fine grinding of course produces a larger proportion of fines. The experiments of Le Chatelier and Bogitch[22] show that the fine material in proper proportion is essential to the formation of a good brick but an excess of impalpable material is just as bad as a deficiency. They found that a brick with 25 per cent of impalpable and 75 per cent coarse material had three times the crushing strength at high temperatures of a brick with the proportions reversed, and they concluded from various experiments that the proportions of 25 impalpable to 75 per cent coarse material represented the most desirable mixture. They suggest, however, that the finer material be prepared by grinding the quartzite in a tube mill rather than by longer grinding in the pans and that it be added to the mixture from the pans in proper proportion. They found that a brick made in this way had four times the crushing strength at 1600° C. of a brick made in the same way, except for the use of screenings instead of the tube mill product. It seems probable that this difference may be at least partly explained by the fact previously mentioned in this paper that the screenings usually contain more than the average amount of clay and related impurities. There may also be something in the physical character of the tube mill product resulting from the way it is ground, which affects its rate of transformation. Coarse fragments change from quartz to tridymite and cristobalite more slowly than small fragments. Fusion tests made by Mr. Taylor on more than sixty samples of quartzite from Pennsylvania show that, with few exceptions, the fusion point was lower for the finely ground material than for the coarser material. In actual operation a small amount of iron from the rollers is added to the mud in the pan and this increases with longer grinding.

Apparently the modulus of rupture, specific gravity, and porosity are not greatly affected by the time of grinding. The experiments of Howe and Kerr[23] show that the time of grinding has little practical influence upon these properties, and they conclude that the time of grinding of Medina (Tuscarora) quartzite may be varied

[22] Op. cit. p. 155.

[23] Op. cit. p 167

100 per cent without seriously affecting the strength of the brick. The changes in these properties are not uniform and they do not run parallel to the changes in time of grinding. Bricks of fine grind make a better appearance than those of coarse grind because the mud from which they are made works easier and the bricks are smoother.

The conclusions of McDowell[24] as a result of his numerous experiments on grinding and burning are that grinding affects the results of the burning. For example, bricks of regular grind increase in cross-breaking strength after each burning and they should be reburned at cone 15 or slightly above the temperature at which medium and fine grind material is burned. Medium and fine grind bricks increase in strength for the second burning but not for more. The crushing strengths of regular, medium and fine grind bricks are to each other approximately as 41 to 84 to 100 and there is an increase in crushing strength with each burning, the finer grind showing the greater increase. The regular grind brick show the greatest uniformity in changes in strength with reburning. The fine grind brick are the most non-uniform in cross-breaking strength when reburned. In strength the medium grind brick is the best on the whole although its compressive strength is less than that of the fine grind brick.

During the grinding process lime is added as milk of lime. The lime is mixed in metal boxes about 3 feet long, 2½ feet wide and 2½ feet deep, in which a shaft carrying two rows of paddles revolves and thoroughly mixes the water and lime. The proportion of lime used varies with the nature of the brick to be made. That for ordinary brick is about 2 per cent by weight. Some manufacturers use as low as 1.85 to 1.90 per cent for 9-inch brick and as high as 3 per cent for special shapes. The lime content should never be below 1.5 nor above 3 per cent, otherwise the bond will be markedly weakened. The modern tendency is to secure the greater smoothness in the mud, formerly obtained by increasing the lime, by finer grinding, as this gives better results.

The lime should be of first-class quality, not overburned or it will not slake well, or underburned in which case it will contain carbon dioxide. If the lime be allowed to stand too long after slacking it loses its "life" and this condition possibly accounts for some failures in brick. One company burns its own lime in order to be assured of fresh, high grade material. So far as could be learned the brick manufacturers have no specifications for the lime used beyond the fact that it must be of "good quality." The lime becomes thoroughly

[24]Op. cit. p. 38. (McDowell tested the effect of reburning on bricks, but does not recommend reburning as a commercial process). Ed.

mixed with the crushed rock in the wet pan and the experienced brickmaker judges the proper consistency of the mixture by its feel.

Sufficient water is added to make the mixture suitable for molding. Too much water makes the brick weak and the mixture runs too readily. Too little prevents proper molding. The ability of different quartzites to absorb water varies considerably. A dense, heavy rock like the Chickies quartzite will not absorb water as readily as the Tuscarora (Medina) quartzite.

Molding.

After grinding and mixing the silica material or mud is carried directly from the pans to the molding floor in wheel barrows or carts. In some plants it is moved by electric cars. Molding is done by the slop mud process or by pounding, depending upon the character of the product desired. Standard 9-inch brick are slop molded and retort open hearth and coke oven shapes are pounded or mauled. One company has adopted the practice of storing the mud for a short time before using because it works a little more smoothly, since it has less bond. In the slop mud process the wet, ground rock is grasped in the hands by the molder and thrown into the molds. When the mold is full the excess mud is scraped or slicked off even with the surface of the molds and the mold is lifted from the brick. The mold consists of loose metal sides which can be stripped off the brick. This metal frame lies on a smooth steel base and considerable care is necessary to keep the molds in first-class condition, owing to the rapid wear by the sharp quartzite grains. The molds are 3/8 to 7/16 inches per foot, or 3.1 to 3.6 per cent, smaller than the size desired in the burned brick in order to allow for the expansion that occurs in burning, when the quartz is transformed into tridymite and cristobalite.

After molding the bricks are placed on pallets, or small metal shelves, which in turn are placed on the drying wagon and run into the drier. One thing observed in going about the plants, especially when most of them were idle during the period of industrial depression following the war, was the very rapid deterioration of the pallets by scaling. This can be avoided by having the pallets enameled, the relative cost of the enameled and the unenameled pallets of the same size being approximately 3 to 2. The life after enameling is very much lengthened. For the larger pieces wooden pallets, or bridged metal pallets, must be used to avoid sagging under the greater weight of the heavier shapes. If wooden pallets are used care must be taken to prevent the full heat of the drier being drawn in upon them otherwise they would soon check, warp and be ruined.

In no plant in Pennsylvania did the writer see any repressing of silica brick. This a common practice with fire clay brick and apparently it is followed in some parts of Europe and in the Western States for silica brick. Before filling the molds are sprinkled with a pure silica sand so that the mud will not stick to the metal. The sand used everywhere in Pennsylvania is the glass sand from the Oriskany formation.

In molding shapes for coke oven and other special purposes the mixture is pounded into the molds with heavy wooden beaters faced with metal. Great care must be used to fill all corners and, in as far as possible, to compress all parts of the bodies to the same density; otherwise the mass will not expand uniformly or burning and cracking will result. It is said that in Salt Lake City all bricks are molded by a repressing machine but they are not good for ferrous work. They are used in non-ferrous plants.

Molding machines. In Pennsylvania all good silica brick are molded by hand although many attempts have been made to manufacture a machine which will do the molding satisfactorily and thus reduce the cost of producing the brick. It was stated by different operators that in their plants two men, one of them a "helper" would mold by hand from 2600 to 3500 9-inch brick in a day. In 1921 the price paid for molding was about 18¢ to molders and 15¢ to helpers per hundred 9-inch equivalent brick.

A good brick machine would increase production enormously and reduce the cost considerably. Several machines have been patented but so far not adopted for regular use. The main difficulties are in the "slicking off" process, in keeping the brick entire, and in getting perfect outlines and uniform density. Some engineers believe that the secret of success lies in a slop mud principle, that is, the mud should be dropped some distance into the molds and thus compress itself uniformly. Others favor the principle of the dry mud process and a mechanical press. One dry mud machine which was patented in 1913 and again in 1917, will make brick but is not yet perfected in all respects. The mud is thrown into the molds automatically by a scoop. It is pressed twice by a hammer during a double, advance and retreat, motion. The hammer is driven through a heavy spring so that it may yield a little in case the pressure should be too great, as from the presence of a piece of metal or some other obstruction between the hammer and the mold. The slicking is done by a horizontal plate rotating rapidly on a vertical shaft. The molds are inverted and lifted off the brick. There is a severe strain on the machine owing to the rapid to-and-fro motion and the pounding operation.

In another type of machine which has not yet been used to any extent the wet mud falls 6 or 8 feet into molds which are arranged in sets of 6, on an endless chain. A roller passes over the material in the molds and it is then slicked off. The molds are automatically lifted from the bricks. Of these machines the former was seen at the plant of the General Refractories Company at Sproul and the latter at the plant of the Standard Refractories Company at Claysburg. Although the machines have not yet been perfected there seems to be no doubt that we will in the future see silica brick commonly made by machines.

Sizes and shapes of brick. The standard size of silica brick is the so-called 9-inch brick which is about 9 x $4\frac{1}{2}$ x $2\frac{1}{2}$ inches. This brick weighs on the average $6\frac{1}{4}$ pounds and therefore runs about $3\frac{1}{8}$ tons to the thousand. Silica brick of other sizes are usually figured commercially as 9-inch equivalents in speaking of the quantities handled. The standard shapes for silica material adopted by the Refractories Manufacturers Association in 1913 and revised to July 25, 1919 include the following:

(1) Standard 9″ shapes (All dimensions in inches)

9″ Straight	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$
9″ Small brick	$9 \times 3\frac{1}{2} \times 2\frac{1}{2}$
Split brick	$9 \times 4\frac{1}{2} \times 1\frac{1}{4}$
2″ Brick	$9 \times 4\frac{1}{2} \times 2$
Soap	$9 \times 2\frac{1}{2} \times 2\frac{1}{4}$
No. 1 Wedge	$9 \times 4\frac{1}{2} \times (2\frac{1}{2} - 1\frac{7}{8})$
No. 2 "	$9 \times 4\frac{1}{2} \times (2\frac{1}{2} - 1\frac{1}{2})$
No. 3 "	$9 \times 4\frac{1}{2} \times (3 - 2)$
No. 1 Key	$9 \times (4\frac{1}{2} - 4) \times 2\frac{1}{2}$
No. 2 "	$9 \times (4\frac{1}{2} - 3\frac{1}{2}) \times 2\frac{1}{2}$
No. 3 "	$9 \times (4\frac{1}{2} - 3) \times 2\frac{1}{2}$
No. 4 "	$9 \times (4\frac{1}{2} - 2\frac{1}{4}) \times 2\frac{1}{2}$
End skew	$(9 - 6\frac{3}{4}) \times 4\frac{1}{2} \times 2\frac{1}{2}$
Side skew	$9 \times (4\frac{1}{2} - 2\frac{1}{4}) \times 2\frac{1}{2}$
3″ Side skew	$9 \times (4\frac{1}{2} - 3) \times 2\frac{1}{2}$
Edge "	$9 \times (4\frac{1}{2} - 1\frac{1}{2}) \times 2\frac{1}{2}$
Jamb brick	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$
Neck brick	$9 \times 4\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{8}$
Feather-edge	$9 \times 4\frac{1}{2} \times (2\frac{1}{2} - \frac{1}{8})$
No. 1 Arch	$9 \times 4\frac{1}{2} \times (2\frac{1}{2} - 2\frac{1}{8})$
No. 2 "	$9 \times 4\frac{1}{2} \times (2\frac{1}{2} - 1\frac{3}{4})$
No. 3 "	$9 \times 4\frac{1}{2} \times (2\frac{1}{2} - 1)$

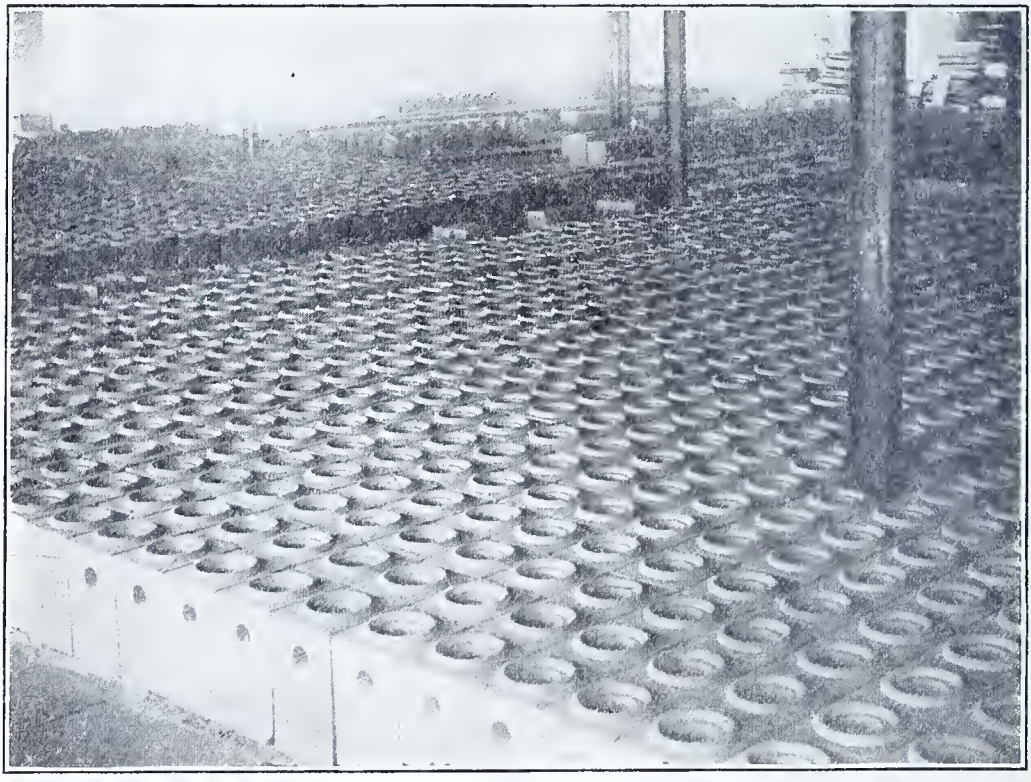
(2) Standard shapes (All dimensions in inches)

Straight	12	×	$4\frac{1}{2}$	×	3		
No. 1 Wedge	12	×	$4\frac{1}{2}$	×	(3	—	$2\frac{3}{4}$)
No. 2 "	12	×	$4\frac{1}{2}$	×	(3	—	$2\frac{1}{2}$)
No. 3 "	12	×	$4\frac{1}{2}$	×	(3	—	2)
Straight	9	×	$6\frac{3}{4}$	×	$2\frac{1}{2}$		
No. 1 Wedge	9	×	$6\frac{3}{4}$	×	($2\frac{1}{2}$	—	$1\frac{7}{8}$)
No. 2 "	9	×	$6\frac{3}{4}$	×	($2\frac{1}{2}$	—	$1\frac{1}{2}$)
Checker brick	10	×	$4\frac{1}{2}$	×	$4\frac{1}{2}$		
" "	9	×	$4\frac{1}{2}$	×	$4\frac{1}{2}$		
Straight	12	×	6	×	3		
No. 1 Wedge	12	×	6	×	(3	—	$2\frac{3}{4}$)
No. 2 "	12	×	6	×	(3	—	$2\frac{1}{2}$)
No. 3 "	12	×	6	×	(3	—	2)
No. 1 Key	12	×	(6	—	$5\frac{1}{2}$)	×	3
No. 2 "	12	×	(6	—	5)	×	3
No. 1 Arch	12	×	6	×	(3	—	$2\frac{1}{2}$)
No. 2 "	12	×	6	×	(3	—	2)
Straight	12	×	9	×	3		
No. 1 Wedge	12	×	9	×	(3	—	$2\frac{3}{4}$)
No. 2 "	12	×	9	×	(3	—	$2\frac{1}{2}$)
No. 3 "	12	×	9	×	(3	—	2)
Straight	$13\frac{1}{2}$	×	6	×	$2\frac{1}{2}$		
"	$13\frac{1}{2}$	×	6	×	3		
No. 1 Wedge	$13\frac{1}{2}$	×	6	×	(3	—	$2\frac{3}{4}$)
No. 2 "	$13\frac{1}{2}$	×	6	×	(3	—	$2\frac{1}{2}$)
No. 3 "	$13\frac{1}{2}$	×	6	×	(3	—	2)
No. 1 Arch	$13\frac{1}{2}$	×	6	×	(3	—	$2\frac{1}{2}$)
No. 2 "	$13\frac{1}{2}$	×	6	×	(3	—	2)
Straight	$13\frac{1}{2}$	×	9	×	3		
No. 1 Wedge	$13\frac{1}{2}$	×	9	×	(3	—	$2\frac{3}{4}$)
No. 2 "	$13\frac{1}{2}$	×	9	×	(3	—	$2\frac{1}{2}$)
No. 3 "	$13\frac{1}{2}$	×	9	×	(3	—	2)
No. 1 Arch	$13\frac{1}{2}$	×	9	×	(3	—	$2\frac{1}{2}$)
No. 2 "	$13\frac{1}{2}$	×	9	×	(3	—	2)

Each of the following shapes has a straight form and three wedge forms. The three wedge forms are the same except that they run, in each case, from (3 — $2\frac{3}{4}$) through (3 — $2\frac{1}{2}$) to (3 — 2).

Straight	15	×	6	×	3
"	15	×	9	×	3
"	18	×	6	×	3
"	18	×	9	×	3
"	20	×	6	×	3
"	20	×	9	×	3

Additional shapes may from time to time be standardized. The Refractories Manufacturers Association, head office Pittsburgh, Pa., also issues tables of shapes required for various structures such as arches, cupolas, etc. In addition to the standard shapes there are many special shapes. In some cases cylindrical holes must be left in the shapes for gas retorts. A number of the companies do not attempt any of the difficult shapes and some of them confine their operations to the manufacture of straight 9-inch brick. The cost of shapes to the consumer could be considerably reduced if he would confine himself strictly to the use of standard shapes because the manufacturing of special shapes raises the average cost (Pl. XV).



Pl. XV. Coke oven shapes in warehouse of Federal Refractories Company, near Alexandria, Huntingdon County.

Drying.

After molding, the green bricks are dried by being run into tunnel kilns on metal trucks. The larger shapes are dried on a hot floor. The driers are heated by live steam in coils and by waste heat from the kilns. The heat is drawn through the driers by means of fans. When live steam must be used until the kilns have been fired this comes from the boilers. The length of time required for drying will vary with the size of the brick, or shape, and with the nature of the rock as well as with the efficiency of the drier. The following are

statements regarding the length of time required for drying in different plants:

2 plants—24 hours for brick and longer for shapes.

1 plant—24 to 36 hours.

1 plant—24 to 48 hours and 3, 5, 6 to 7 days for various shapes depending on their size and form.

One plant contemplates drying ordinary brick in 10 to 12 hours with an improved drier which was being installed at the time of the writer's visit.

Silica brick shrink very little on drying compared with clay brick and for this reason they can be dried more rapidly. If wooden pallets are used the full heat of the drier must not be turned on them at once.

Burning.

The burning process is the most important of all those through which the brick passes because the properties of the brick depend so much on it.

Silica brick kilns: In Pennsylvania all burning is done in circular, down draft, tunnel kilns. The diameters of these in use and the respective average capacity are as follows:

Kilns in use in Pennsylvania

Diameter in feet	Capacity in 9-inch brick	Number in use
32	80,000-90,000	85
36	125,000	27
38	140,000	36
40	170,000-175,000	44

Some operators do not like the larger kilns because, it is claimed, the temperature is not so easily controlled and if anything goes wrong, the loss is greater. Others regard them as giving more uniform results on the average than smaller kilns. Large kilns have a distinct advantage for a big output and there seems to be a tendency to build them in the larger plants. The kilns are built of red brick and second grade fire brick on the outside and first grade fire brick inside. Fire clay is used for mortar and around the fire boxes a refractory cement is employed. The kilns are bound by heavy iron bands (Pl. VIII).

There are eight fire boxes in the small and ten fire boxes in the larger kilns. The size of the fire boxes depends on the opinion of

the builder and the nature of the rock to be burned. In one plant they are 42 by 44 inches, in another 60 by 48, and in a third plant it was found necessary to increase the size of the boxes from 60 by 36 inches to 60 by 48 inches in order to secure sufficient firing capacity for rock requiring more than the average burning temperature. In kilns with ten fire boxes one company has adopted the custom of leaving four of the boxes dead until the kiln becomes heated up through the period of "water smoking." This results in considerable saving of fuel. The fire boxes are topped by arches and the fire is built on grates over an ash pit. The roof of the kiln is a dome with port holes at intervals. These are usually left open until the fires get well started and some operators keep them open for a number of hours for the purpose of water smoking the brick, or driving off the water left by incomplete drying.

The heat from the fire boxes rises along the under side of the kiln arch and then descends through the pile of brick to the openings in the floor leading into the tunnels beneath the floor. These tunnels lead to the center of the kiln and a main tunnel runs from this point to the flue in the stack. As a rule two kilns are connected to separate flues in a single stack. A few plants have kilns with individual stacks.

An interesting experiment was to be tried out at the new plant of the Van Dyke Silica Brick Company at Van Dyke, Pa., where an extra 18-inch flue was being added to each kiln on the opposite side from the main flue. The object in adding this flue is to prevent a general drift of the currents of heated air toward the main flue and to draw a proper proportion of this hot air towards the opposite side of the kiln. A proper distribution of the heat in a kiln prevents soft brick occurring in any part of the kiln and it also reduces the time of burning. There seems to be little danger of unequal distribution of heat if a tunnel kiln is properly constructed. In some of the kilns first built the tunnels under the floor were not properly arranged to prevent some of the hot air going directly into the main tunnel. In that case there was a tendency for the heat to pass directly toward one portion of the kiln instead of traveling equally from all parts toward the center before passing to the flue. The tunnels from the kilns are connected to tunnels leading to the driers so that waste heat is drawn from the kilns into the driers, by exhaust fans.

At the Standard Refractories Company plant at Claysburg the heat from the kilns is used to generate steam for the production of electricity which is used to operate the plant and to light the town. At this plant there are 4 boiler stacks each 176 feet high and the kilns are connected with them so that when the draft in the kilns

is poor it may be aided by connecting the tunnel with the stacks instead of with the ordinary flues.

Filling a kiln. In filling a kiln the green brick are piled on edge and in rows on top of one another. Each row may be either parallel or transverse to the one below it. Layers of burned brick are placed in the kiln at irregular intervals to distribute the load and stabilize the pile (Pl. XVI). Shapes are very carefully set in the upper part of the kiln on top of the standard sizes.

Pl. XVI. Interior of kiln, Federal Refractories Company, near Alexandria, showing method of stacking brick. Green brick are piled on edge and supported by layers of burned brick laid flat.

Temperature of burning. In most plants silica brick are burned to cone 18 (approximately 2700° F. or 1500° C.). In some plants they are burned to cone 19. Some of the Chickies quartzite, which is a comparatively pure, dense and very hard rock, seems to require a little more burning than the Tuscarora to produce a strong brick. It has been burned in the Lavino Refractories Company plant at Womelsdorf, Pa., to nearly 2800°F. which would be around cone 20 (2786°F. and 1530°C.). LeChatelier and Bogitch consider that the furnaces never reach the actual rated temperatures of the cones. From their experiments in ceramic furnaces they have found that the time factor is an important one and that the cones soften at 70° to 100° lower than their rated temperatures, which are determined from rapid heating. They believe that bricks are, therefore, never actually fired at temperatures much above 1400° C. Some writers state that owing to the great permanent expansion in silica brick during the transformation of the quartz the brick should, if possible, be burned to as high a temperature as they will reach in use. This would be a desirable condition but it is obviously impossible to reach it in all cases because some furnaces reach temperatures close to the melting point of the brick. The brick do not fail, however, because only a small portion is raised to this maximum temperature at any one time. It is impossible to prevent a large amount of expansion even in the best burned brick and some think there is little advantage in raising the temperature above 1450°C.

For burning silica brick, a good grade of low-sulphur coal is required. At one plant a wise economy is the use of a lower grade coal for the earlier days of the firing process, before the maximum temperatures are reached, and a high grade type for the later stages when the highest temperatures are attained. The cost of coal is an important factor in making brick. The amount of coal burned per thousand brick is estimated at 1½ to 2 tons.

Duration of burning. Opinions vary regarding the length of time kilns should be fired. Practice in Pennsylvania runs from 7 to 12 days, depending upon the method of firing, the nature of the quartzite, and the size of the kilns. For example, one company states that firing lasts 7 to 9 days for 32-foot kilns and up to 12 days for the large kilns 40 feet in diameter. Another company claimed that with their improved kilns 5½ days is sufficient. In most plants firing runs 9, 10, 11 and 12 days depending upon the size of the kiln. It is very important that the kilns be allowed to cool slowly because one of the difficulties with silica brick is in their cracking when exposed to rapid changes in temperature. It is necessary to allow

[25]Op. cit. p. 159

from 6 to 10 days for the cooling operation and the heat from the cooling kilns may be utilized for power, for drying brick or for preheating freshly charged kilns. It has been suggested that in cases where brick are in great demand the period of cooling could be shortened by blowing in air which is falling gradually in temperature. This would obviate the risk of cracking the bricks and especially the shapes, which are placed near the opening and which suffer most when air at normal temperature is allowed to enter any of the openings in the kiln.

Some brick manufacturers water smoke a kiln before attempting to raise it to a high temperature. This is done by firing gently for 36 to 48 hours with ports open. All water is driven from the brick before they actually begin to burn. The value of this operation seems to vary greatly in the opinion of various operators even in different plants of the same company, so the necessity for it probably varies with the efficiency of the drying operation. This operation is partly dependent upon the character of the rock.

In firing a kiln some companies have the fires fixed regularly every hour for convenience and accuracy. Others give close attention to firing only as needed.

Firing should not be too rapid, otherwise there will be too great an expansion of the brick when the transformation of the quartz begins, and the brick will collapse or crack before the cementing network has properly formed. Le Chatelier and Bogitch suggest that the temperature might be raised rather rapidly to the point where the large grains of quartz would begin to transform directly to cristobalite, which would be around 1250° C. When this temperature is approached, the firing should be much slower. It is considered better to burn bricks for a long time at a low temperature than to burn them for a short time at a high temperature because in the latter case very little but cristobalite is formed and the bricks are weak. The temperature should not be raised much above 1470° C. in burning, otherwise tridymite will not form.

The valuable experiments of McDowell, previously mentioned in this paper, indicate that although brick may be improved by reburning, better results could be obtained by prolonged burning at a proper temperature. The object of the process is to completely transform the quartz into the forms of silica stable at high temperatures and to develop a network of tridymite, which has the least thermal expansion of any of the forms of silica. The more tridymite formed the stronger the brick. Investigation of bricks which have been heated in furnaces for long periods show that a great deal of tridymite has formed.

QUANTITY, PRICE, AND MARKET.

In 1909 Mineral Resources of the United States first mentioned the production of silica brick, but gave no separate figures of output.

In 1910[26] the production for the country was 145,779,000 9-inch equivalent brick with a value of $3,289,028. Of this production Pennsylvania supplied 112,633,000 or 77.26 per cent. The remainder came from Alabama, Georgia, Colorado, Illinois, Indiana, Missouri and Montana. In 1911 owing to a slump in markets only 104,483,000 brick were produced. In 1915 the production rose to 130,244,000 at an average price of $23.34 per thousand. In 1918 the enormous production of 336,562,000 brick was reached and of this production 69 per cent of the quantity and 67 per cent of the value came from Pennsylvania. The average price was $59.39 per thousand for the United States, and $57.27 for Pennsylvania. In 1920 the production for the United States was 250,582,000 at an average price of $60.17 per thousand. Of the production in 1920 Pennsylvania furnished 73 per cent of the quantity and 71 per cent of the value. The other States which reported some production were Alabama, California, Colorado, Illinois, Indiana, Maryland, Missouri, Montana, Ohio, Utah and Washington but apparently some of these States, as Illinois and Missouri, manufactured brick from material quarried outside their boundaries as no suitable materials are known to have been quarried in these States. Before the war the prices seem to have averaged about $22 to $23.50 per thousand. In 1921 the price in Pennsylvania was around $37 per thousand.

The estimated possible production in Pennsylvania, according to figures collected at the plants, if all plants now in existence were working at full capacity, would be 1,230,000 9-inch equivalent brick per day.

It is difficult to find a definite statement regarding the date of the manufacture of the first silica brick in the United States, or in Pennsylvania. The writer was informed while at Hyndman, Pa., that the first brick of this type were made at that place in 1882 but this is not verified by several printed statements. In a paper by C. B. Stowe, president of the Stowe-Fuller Company of Cleveland, Ohio, and one of our authorities on such subjects, which appeared in the Brick and Clay Record, he states that the first silica brick were made by J. Park Alexander of Akron, Ohio, about 1867. These were modeled after the dinas brick of England and were made from quartz pebbles from a conglomerate found near Akron. This type of brick was later made on a small scale by Isaac Rees & Sons Company at Manorville, Pa. The material used was then known as

[26] U. S. Geol. Survey Mineral Resources 1910, Pt. II, p. 550 (footnote), 1911.

the "Juniata Ganister," which is the quartzite so generally used today and known as the Tuscarora or Medina. In 1887 the Harbison & Walker Company which in 1902 was merged into a great corporation, the Harbison-Walker Refractories Company, began production of silica brick at their Star works in Pittsburgh[27]. These brick also were made from the Tuscarora quartzite and competed successfully with those from Europe. Since that date the silica brick industry has gradually developed to its present importance. The most rapid strides in this industry were made when this type of brick began to be used on a large scale for open hearth furnaces and again when it became generally adopted for coke oven construction. The dates of establishment of the various plants throughout Pennsylvania are mentioned under the description of the operations of the various companies.

Pennsylvania silica brick are shipped to almost all parts of the world, including England, Italy, Japan, China, Brazil, Chile, South Africa, Greece, France, Central America and Canada. Canada is a heavy buyer. Comparatively few brick are shipped to Europe in normal times; most of the European countries mentioned secured the shipments during the war.

Some companies specialize in certain lines of brick. One company does not make coke oven brick whereas another will make all shapes. A company like the Harbison-Walker Refractories Company manufactures every conceivable size and shape but all types are not made in all of their plants. At their East Downingtown plant they do not make coke oven brick. Another company specializes on retort, glass tank and copper furnace brick as well as on open hearth types but manufactures practically no coke oven material. By far the greater part of the silica brick manufactured in Pennsylvania is used in the metallurgical plants of this and neighboring States.

[27]Ries, H. and Leighton, H., The history of the clay working industry: John Wiley & Sons, New York, p. 210, 1909.

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